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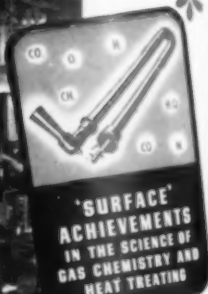
Metal Progress



The American  Society for Metals

OCTOBER • 1945

Atmosphere Hardening



↑ View showing charge end of hardening furnace units equipped with magnetic vibrator charging mechanisms. Note 3 RX Gas Generating Units in foreground at right.

← View showing 3 RX Gas Generating units, Control Panel and discharge end of recirculating-air draw-furnaces.

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METALLURGICALLY
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October, 1945

Volume 48, No. 4

Metal Progress

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By Frank G. Norris
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Wartime Changes That Will Affect Peacetime Steelmaking

MORE water glideth by the mill than wots the miller of" is a Shakespearean wording that describes the changes in the steel industry during the last five years; and "reconversion" will never bring it back to where it was in 1940. Perhaps the least reversible effect of the war is that the ore reserves of the country have been depleted at a rate never before attained. This fact has been mentioned many times, though it is usually concealed by calling simultaneous attention to the record breaking production of steel ingots which are never seen on the fighting fronts but are a part of the measure of a nation's ability to defend itself. In other words, the means to convert iron ore to steel is the foundation of the Arsenal of Democracy.

Another far reaching result of the war on the steel industry is the construction of many new plants which have considerably increased the steelmaking capacity of the nation. However the increase in other industries has also been large. While the capacity of the steel industry was being increased less than 20%, the capacity to make other products often regarded as competitors of steel was increased several hundred per cent.

The steelmaking capacity of Jan. 1, 1945, is rated at 95,500,000 tons of ingots and castings per year, an increase of about 13,750,000 since Jan. 1, 1940. The blast furnace capacity is 67,300,000 tons per year of pig iron and ferro-alloys, an increase of 11,500,000 tons. Obviously

the industry is now using a greater amount of new iron to make each new ton of steel. The maximum ore production was 105,526,000 gross tons in 1942.

Two important questions occur to one who ponders these figures, "Are the ore reserves adequate to support such great production? Can a peacetime economy absorb this much steel as well as the product of the aluminum and magnesium and other metal smelting plants?"

The first question has been brought to public attention by at least two articles in the *Saturday Evening Post*, "The Coming Crisis in Iron", in the issue for Nov. 14, 1942 and "The Mine Nobody Wanted", June 19, 1943. "The war's extraordinary demands for steel, forcing Lake Superior ranges to provide around 100,000,000 tons of ore yearly, have recently high-lighted the fact that the finish of really high grade ores in that region is rapidly approaching." Such a statement with no qualification is surely not designed to instill confidence in our industrial future geared to steel production. A more balanced picture is presented by Elmer W. Pehrson in *Mining and Metallurgy* for April, 1945. While he admits that the cream of our Mesaba ores which can be mined cheaply and used directly in the blast furnace without prior treatment (and which now accounts for half of the total production of the country) is distinctly limited, the remaining supply is estimated at 17 years at the 1942 rate of extraction, though it will probably be longer because the rate of production can be expected to decline. On the other hand iron is the fourth most common element in the earth's crust, comprising about 4.2% of the lithosphere, and being exceeded only by aluminum, silicon, and oxygen. Therefore the time will never come when iron, steel, aluminum, and magnesium cannot be obtained in whatever quantity needed — at a price. Processes for producing high grade concentrates from low grade ores will be perfected, sintering or

similar preparation of the fines will be widely used, and both the blast furnace and openhearth will adapt their operation to use efficiently the material at hand.

If the above discussion is too general to fill the immediate demands of practical men, more specific comfort can be obtained by selecting the leanest ore there is in one of our ore books and comparing the analysis with the ore described in any current account of British practice. In other words iron ore is not a mineral of some specified (meaning "desired") iron content, but rather it is a mineral that somehow or another can be used as a commercial source of iron. Although our concept of what constitutes either "iron ore" or "steelmaking" may be due for considerable revision, the ore reserves will last at least as long as our present civilization.

The question of our ability to use steel and light metals in the near future involves so many considerations besides metallurgy that the answer is much less certain. Consider the following statements from a recent (June 28) issue of *Iron Age*: "The bulk of the (Lone Star) plant stands idle in the wilderness. . . . No more than two or three Defense Plant Corp. aluminum reduction plants will be in operation after the war, possibly only one. Aluminum sheet mills at Spokane and Chicago are considered to be white elephants with no possible usage now in sight."

On the brighter side of the picture there is the statement: "Major producers now consider themselves underbuilt in the tin plate and sheet categories." There is also the accumulation of several years of civilian demand.

Competition With Other Materials

Apparently the important postwar competition facing the steel industry is not whether your employer or mine gets an order from some important customer, but whether steel or some other material will be used for various applications. There are at least three classes of materials that in some use compete with steel. These materials are the light metals, glass and other ceramic products, wood and products derived from vegetable sources such as plastics and paper. In some uses the "victory models" are clearly substitutes and will be dropped as soon as possible. In others the competitive materials have definite advantages in their own right.

At present many of the disadvantages of steel—and it has some disadvantages—are tolerated simply because it is abundant and cheap. As the trustee of a vital national resource the steel industry should be informed as to where steel

serves best and insist that other materials be used for all other purposes. For example, if tobacco is reasonably usable in a cardboard box, or unprotected by metal foil, can the national economy afford to squander metal for this purpose? If auto bodies could be made satisfactorily, better and cheaper from soy beans, why should anyone want to make them from steel? (Possibly this is a hypothetical question, but you get what I am driving at.)

Iron is still the master metal and has plenty of bulwarks from which it can never be displaced by either aluminum, paper, plastics, or any other substance. One example will suffice: At the heart of every electrical machine, whether it be a huge generator or a tiny motor or delicate meter, will be found a core of iron.

Furnace Design Apparently Stabilized

The war period has not seen any radical change in furnace design. The openhearth is still struggling along with the arrangement that Mr. Ramseyer (I wonder what improvement he's made) poked fun at ten years ago by saying it was like trying to heat a pan of water by blowing a candle flame across the top after first taking the precaution to cover it with a blanket of insulation!

Several of the new shops have included a tilting openhearth with about five or six stationary ones. There is a decided preference for a shop of this size and arrangement instead of 12 or 14 furnaces in a line. (A notable exception is the new plant at Homestead.) There has been a definite tendency toward liquid fuel, either oil or tar, in preference to producer gas, and this has influenced furnace and port construction.

Liquid fuel has two, or possibly three, advantages: All during the war the emphasis has been on tonnage, with cost the second consideration. Some of the gas producers that have been displaced probably never will be put back after the war because oil is definitely a low sulphur fuel. A producer gas shop would be seriously handicapped in trying to meet the sulphur requirements of the steels for many exacting uses. This is not saying that all of one's sulphur troubles are solved by using oil, or that fairly low sulphur analyses are never made with producer gas, but generally the oil furnace has a better chance to make a fast, low sulphur heat.

There are two disadvantages, both due to oxidation. One is that a little more pig iron is required for a given melt and the openhearth yield is lower. The other is that, for a given set of conditions in FeO and residual manganese, the

oil furnace will require a slightly larger manganese addition to meet the specification.

The other possible disadvantage of producer gas is that coal is not always available! Of course oil may not be available either, but thus far the antics of the leaders of the coal miners' unions have not been such as to inspire confidence in the dependability of their product. Oil is not yet handicapped by this threat.

One minor change in furnace construction directly related to maximum production for war is the accommodation for flush slags in stationary furnaces. In times of slack operation scrap is plentiful and the tendency is to make steel from as little pig iron as possible, consistent with fast charging. In recent years, the shortage of scrap was aggravated by the entrance of new capacity demanding raw material for its charges. The only way more steel could be made was from more pig iron. Shops that never before had charged enough iron to flush, rebuilt their furnaces with flush holes.

The front flush is a popular arrangement. It allows better control of the flush and does not present the problems of maintenance of the usual flush spout. One disadvantage is increased trouble in the pit. In general a slag that has a tendency to foam should be flushed off to avoid loss of time. Such a slag would freeze up and not flush from the usual slag flush hole of fixed height, placed at the rear, but it can usually be flushed from the front.

This is a change in furnace construction and slagging that is likely to be retained in peacetime operations.

Alloy Steels From the Openhearth

One of the outstanding changes in steelmaking practice has deep-rooted causes and far-reaching effects. This change is the development of the NE series of alloy steels which is reflected in the increase of the amount of alloy steel made in the openhearth furnace. In its present embodiment as "H" steels, this subject is discussed at length by Mr. Ekholm on page 673 of this issue.

Early in the war, plans were made to make as much use as possible of the alloying element molybdenum, because of the favorable position of our domestic resources, and to substitute manganese for nickel in many applications.

The openhearth did such a good job of easing the load on electric furnaces, that at times it has appeared that electric capacity was over-extended. I don't know of anyone who ever missed the boat by being on board too soon, but it seems that I recall something about too little and too late.

Criticism of idle capacity, therefore, should be tempered by such thoughts. The future ownership and operation of the steel plants owned by Uncle Sam's Defense Plant Corp. is of course a matter of conjecture. It seems reasonable, though, that new plants in suitable locations will be operated, and that other plants with high costs due either to obsolescence—or even new ones poorly located—will be at a disadvantage in postwar competition and remain idle.

In this respect the future of the new steel plants of the West is another unknown. (Of course at one time it seemed rather strange to build the Gary steel mill in the middle of a sand dune.) Perhaps the beautiful lawns and model schools of Gary should be visioned as possible surroundings of some of the new mills that are now out in the middle of nowhere—no grass, no trees, no houses, no stores; just steel mill and sunshine. This is the reason for the announcement that the center of steel production has again moved slightly West, and is now a few miles from Massillon (Ohio). Just as there are no crowds of people at the center of population, there is no steel mill at the center of American steel production!

One openhearth problem that is affected by the greater production of alloy steels of all kinds—but especially the steels of lower alloy content—is centered around the question, "What is alloy scrap worth in comparison with carbon steel scrap?" If the alloy content can be used to save a ferro-alloy addition, the scrap should be worth a premium. On the other hand, if the scrap is used for an ordinary heat the alloy content is not only worthless, but a detrimental source of contamination. There is a challenge to prevent these vital alloys, diluted with iron, from being squandered.

Use of copper-clad scrap has raised a question of, "What is copper-bearing steel?" The quick answer that it is steel which contains copper is not right. The answer that it is steel to which copper has been added is not quite right. The answer in the book is that copper-bearing steel is steel containing 0.25% copper made by adding copper intentionally.

The question is by no means an academic one. At one time copper heats were made by adding pig copper, sometimes with the charge, sometimes just before tap, sometimes both with the charge and with a small adjustment before tap. It was considered good practice to segregate copper-bearing crops to charge back in copper heats. Then instead of pig copper, scrap copper of some kind was used. Then came the war with copper-clad steel and restrictions on pig copper.

Copper-bearing heats were made by charging the copper as copper-clad scrap. This practice and product was about parallel to the old practice.

One night in the rain a stock boss had seven furnaces charging at once and was short three men and had a green craneman. When he went home he thought he had done a pretty good job to have had only a couple of small delays. There was no record of any copper scrap having been charged, but the next day there was a copper heat. The interpretation of those who interpret such rulings was that this heat could not be used for copper-bearing orders because it was made accidentally. The inference is that when a drop of rain meets an atom of copper it will say, "What are you doing here?" If the copper says, "I was put here for the purpose of keeping you from rusting this steel," the rain will say, "Oh, pardon me, I guess I'd better be running along." So it will run off the surface and not do any damage. But if the copper says, "Why I just happened to be around, but not for any reason in particular," then the rain will say, "I guess I'll pick up some SO_2 and maybe open up a pit of rust."

Oh, well, I guess it takes all kinds of rules to win a war!

Deoxidizers and Intensifiers

Closely related to the restriction in the use of pig copper was the request to steelmakers to use as little aluminum as possible. We figured this was a small sacrifice compared with remelting perfectly good aluminum sauce pans, and absolutely abolished aluminum except for the small amount used in the molds.

The use of rasorite as a ladle addition for rimmed steel for some reason or other is a local problem, because there were many plants that were not able to make it work. Some tried it for killed steel and some tried it in the molds and I guess others couldn't understand *why* it should work and just didn't try it.

Some people kind-of grin and ask me what we are using now. We are back to using aluminum, because it is cheaper than rasorite. Before the war we were paying 17 or 18¢ a lb. for bar aluminum; now it is 6 or 7¢. We have learned, however, that should reasons of economy or

emergency demand it we can get along with very little aluminum.

I say "very little" because none of the other deoxidizers quite takes the place of aluminum in the molds. This apparent paradox may require a bit of explanation. The action of borax or rasorite in the ladle is apparently to deoxidize. Any high school chemistry student knows that a borax bead has a high power to dissolve many oxides. A combination of high solubility and low concentration of FeO in the borax removes FeO from the steel by extraction, as surely as does precipitation of oxygen by the formation of insoluble oxides which is the normal process. Of course the equilibrium concentration is higher, which explains why this borax or rasorite treatment cannot replace aluminum for fully killed steel.

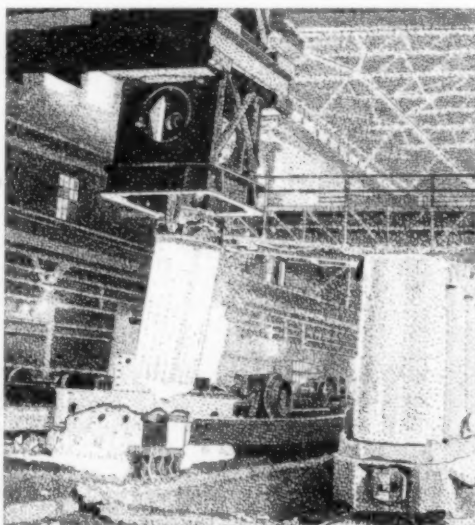
Apparently, deoxidation is only an incidental effect of the aluminum added to the mold to control rimming action. Sometimes a few pellets of aluminum added to the top of a rimming ingot, after pouring is finished, will cause the "bottom to drop out", lowering the level of the liquid. I have never been able to account for this effect in terms of a change in oxygen concentration. It seems as if the Al_2O_3 formed is of greater importance to the action than the oxygen entering into its formation. (I can hear a voice resembling that of Dr. Jeffries ask, "Why not just add a wee bit of colloidal alumina?")

After the discussion of borax the logical next

step is mention of the discovery that boron is beneficial, which is one of the important developments of the last few years. People are inclined to consider boron as in a little different category from the other alloying elements. In fact it isn't even considered an alloying element, but rather its presence in minute amounts produces what is often called a "needled" steel.

A rough-and-ready way to explore new territory is to make a series of short expeditions from various points and if the general trend is con-

sistent to assume that nothing startling has been overlooked. Study of a series of iron-boron alloys by convenient steps, starting with iron of no boron, indicated that boron was a hardening agent and made the iron very difficult if not impossible to forge. Then came the discovery



that very minute traces of boron are quite different from the smallest amount previously thought worthy of study. These almost infinitesimal residuals, almost too small for analysis, are what are now in the spotlight.

Hydrogen is another element that has extended the range of analyses, usually reported. Study of hydrogen began with precise chemical and analytical tests and passed to the stage of accumulating information on its effects. There is room for considerably more accurate information on means for its control, particularly in the steelmaking process.

Control of Refining Operation

The general control of the openhearth process has made rapid progress. In the first place "control" has come to mean many things. Almost any observation or analysis of slag is referred to as "slag control"; various meters, valves and instruments around the furnace are incorporated into a system of "automatic control"; and now an ingenious method of juggling numbers is part of "quality control"!

The most important aspect of any of these control systems is that none of them is the entire answer or the missing link to fool-proof steel-making. Let me add very quickly that each has a field of usefulness that can make a valuable contribution to the efficiency and quality of steel production.

The opening remark of a paper on "Openhearth Furnace Control" read by M. J. Bradley to the A.I.S.E. in Sept. 1940 was, "The methods of controlling an openhearth furnace have changed considerably during the last five years." Such a statement cannot be made in the fall of 1945. There may have been some improvements in details here and there, but the instrumental equipment and methods in use today are those described in Mr. Bradley's paper. A difference exists in the generality of their use and their understanding.

One of the great unknowns of steelmaking is temperature. One gets the impression that the English have progressed further in this problem than we have. Several of their papers report, more or less incidentally, the measurement of bath temperature. The immersion thermocouple seems to be in fairly general use. Perhaps the same impression would be gained if knowledge of our own conditions was limited to reports in the technical literature. Regardless of reports of various methods, all of which are promising, there is still enough steel to make a battleship tapped on the indication of a cut rod, or a test

slowly poured from a slagged spoon, or (especially in electric practice) of a set test.

A. J. Fisher has written three papers (two for the Association of Iron and Steel Engineers and one for the A.I.M.E.'s Openhearth Committee) that are required reading for anyone with a serious interest in combustion. He emphasizes the distinction between temperature and radiation, and points out the latter's importance. Starting from the premise that, in general, any material that can be metered can be regulated by automatic control equipment, it develops that the inter-relations among the various components of the openhearth system are such that probably only one element can be controlled arbitrarily. There can be automatic control of furnace reversal, based on one factor like constant time interval, or temperature differential between two selected points, or of draft, or flue gas analysis, or furnace pressure, or roof temperature, or fuel-air ratio. This control can be on either fuel or air.

There have been various arguments for and against details of specific installations, as well as more philosophical arguments about the merits of control in general. There undoubtedly exists equipment that is difficult to maintain by the available workmen, and the purpose of which is not thoroughly understood by the man running the furnace. There are also shops that would benefit by additional knowledge of furnace condition that could be furnished by proper instrumentation. New construction of the war period has also provided a proving ground for many installations which are being watched with interest by other operators.

The press of production for the armed forces has also retarded some experimentation. Mr. Fisher remarks that they were doing so well that they hesitated to make changes which, though of possible benefit, could very easily prove to be detrimental. Thus when the urgency of wartime production is slackened and wartime restriction of purchases is lifted, there is certain to be a period of experimentation and purchase of new equipment.

There has been a gradual development of closer chemical control and of more rapid analysis so that the data could be used promptly and not merely recorded as a history of what had been done. Spectrographic equipment, unknown even in research laboratories a few years ago, is now the source of information on the charging floor that is used to adjust the final alloy additions. This is an outstanding current example of the practical application of pure science.

Before the war bottom pouring brought to mind a crowded pit and a lot of work, first in

setting up runners and later in stripping the ingots. Frequently graphite was used as hot top insulation which added to the general dirt and disagreeable conditions in the openhearth pit. Part of this situation was due to fixed constructions—the shop was not properly planned for the necessary operations. The new shops have provided covered mold yards and buildings designed for the preparation of hot tops. "Sweat houses" for heating cold drags of molds are also in use. Bottom pouring on buggies fits this method of pouring more easily into the routine of a busy openhearth shop, and makes it not much more arduous or space consuming than the usual top pouring.

Refractories

A fitting introduction to discussion of war-time changes in materials is found in two speeches by Portia in Act V of the Merchant of Venice:

A substitute shines brightly as a king,
Until a king be by; . . .
How many things by season season'd are
To their right praise and true perfection.

Not so many years ago, nothing but the best Austrian magnesite (after careful contamination with the chief material that it was expected to resist) was good enough to be entrusted with that highly important responsibility of serving in an openhearth bottom. Then American magnesite from the state of Washington was cautiously tried, but the length of life and the vicissitudes of service conditions prevented accurate comparison of the merits of the two materials. Domestic magnesite gave a good account of itself—but still, if a superintendent wanted to be *real* sure of a good job he would use Austrian magnesite, assign the best helper on each turn to the task of burning it in for a period of 10 days to two weeks, chill the bottom to crack it, then dress over the cracks, tap a heat of slag, and begin to think of alibis for any trouble that might develop while that furnace was still the newest bottom in the shop!

Now it just happens that in His infinite wisdom the Great Architect of the Universe has seen fit to bathe the surface of most of our planet with a solution containing, among other things, 0.2% MgO, chiefly in the form of $MgCl_2$ and $MgSO_4$, and to provide man with the sagacity to make use of this bounty. So about 1935 the Marine Magnesium Products Corp. was operating a sea-water plant in California and recovering $Mg(OH)_2$ for pharmaceutical uses. Magnesium Elektron Ltd. claims to be the first producer in the world of sea-water magnesium on a commer-

cial scale. There is one ton of MgO in 112,000 gallons of sea water, and a cubic mile of sea water contains $8\frac{1}{2}$ million tons of magnesia. There are a lot of cubic miles in the ocean and hence practically no risk of depleting the supply, even though we use some of this salt to make the metal magnesium.

Careful control of the size distribution of the material has contributed largely to the success of rammed-in bottoms. The material cost is greater than for a burned-in bottom, but the total cost including labor and fuel is in favor of the rammed bottom. The time saving is of greater importance during the urgency of wartime demand than it may be in periods of slack operation. It is well to remember that, if there is sufficient clearance between the top of the furnace and the floor crane, a cement mixer on a scaffold above the furnace roof will deliver the ramming mixture inside the furnace more efficiently than it can be handled in charging pans.

An all-basic furnace is still considered an experiment that will not quite justify its cost except possibly for a small one. Raymond E. Birch has summarized this situation: "No matter what is accomplished with basic refractories within the next decade, many will venture to predict that the openhearths constructed from these more expensive refractories will be few in number as compared with those for which silica brick will still be considered the most economical refractory. However, the great progress in recent years with basic refractories has made it reasonable to expect that in time they will be successfully applied in some instances to the full span of the openhearth roof."

In England the war has led to the improvement of dolomite brick. One interesting effect of this development is the influence of the ladle lining on various reactions with liquid steel and slag. Desulphurization of iron with sodium carbonate is said to be much more efficient in a basic lined ladle. There are also reports of less trouble with phosphorus reversion during the pouring of a basic ladle.

Fluxes

Whoever first discovered that fluorspar is a good basic flux did a better job than he probably realized at the time. The war has developed several competitive uses for spar, thus impelling the openhearth to search for a substitute. Practically every material with any reasonable hope of success (and some without much reason) was tried with the final conclusion that the best substitute for crude spar is spar concentrate.

The list of materials tried includes fluorspar and mill scale, mill scale alone, rock salt or various other forms of sodium chloride (the slag probably didn't pay much attention, but went ahead and volatilized the salt no matter whether it was fine, coarse, crystalline, or briquetted), ilmenite, aluminum dross, vanadium dross, bauxite, and topaz. In answer to a question about the post-war possibilities of these various substitutes, Vernon Jones says: "Aluminum dross does not do everything that spar does, but considering the economics, it is cheaper than fluorspar."

Two important wartime projects of the Bureau of Mines have been sufficiently misunderstood that they call to mind Aesop's Fable on The Wild Boar and The Fox:

A Wild Boar was whetting his tusks against a tree, when a Fox, coming by, asked why he did so. "Boar," said he, "I see no reason for it; there is neither hunter nor hound in sight, nor any other danger that I can see at hand." "True," replied the Boar, "but when the danger does arise, I shall have something else to do than to sharpen my weapons."

It is too late to whet the sword when the trumpet sounds to draw it.

Both of these projects are ideally suited for government support; they are of fundamental importance in developing our domestic resources rather than of immediate commercial application; they are of potential value to the entire industry and thus to the nation as a whole rather than to any one section; they do not put the government in the position of competing with private consultants.

One of these projects is the production of electrolytic manganese from low grade domestic ores. The product is pure manganese in the form of small square plates about 0.05 in. thick. Samples were submitted to most steel companies. The question was, "Neglecting all considerations of cost, if this were the only source of manganese, could you use it to make your present grades of steel?" As far as I know in every case the answer is "Yes".

Using the ladle analysis as the indication of performance, we demonstrated at Wheeling Steel that satisfactory recovery could be obtained with electrolytic manganese as either a furnace or ladle addition. Some other companies carried the investigation further and made an exhaustive comparison of various physical properties. The general conclusion seems to be that electrolytic manganese is as good as, but not particularly better than, standard ferromanganese, unless it is used where advantage can be taken of the absence of carbon. This situation is like the use of chemically pure sodium chloride to melt

the ice from a slippery sidewalk. It will do the job satisfactorily, but no particular benefit is derived from its extreme purity.

The other governmental project referred to is the development of sponge iron processes. Sponge iron itself is neither new, having been known in early times, nor rare, being now produced as a transition stage in every blast furnace. One blast furnace superintendent remarked: "All I would need to do to make sponge iron would be to cut off the lower half or two-thirds of my furnace." Another piquant comment on the sponge iron situation is that of Camp and Francis: "The ease with which iron ores are reduced makes the direct process appear enticingly simple and logical."

The great steel mills of the country are located according to the formula "Where Coal (meaning not just any coal, but coking coal of the proper sulphur content) Meets Iron". One of the interesting possibilities of sponge iron is that of freeing a steel plant from the fetters of King Coal. Its use of inferior fuel seems at the moment of greater importance than the fact that sponge iron is nearly free from carbon.

One of the Bureau's plants is located in Texas. The preheated ore is reduced by a gas prepared from natural gas. The 50% Fe of the ore is concentrated to 75% in the sponge iron, of which about 60% is metallic. The carbon is about 1.5% and silica plus alumina around 15%. There is no agreement on just how material of this general analysis should be used. It has been considered as a substitute for ore (that is, a sort of "super" charge for the blast furnace), as a substitute for pig iron in various steelmaking processes except the bessemer, as a substitute for scrap in the openhearth or electric furnace — or, not as a substitute for anything, but as the basis for a new process designed to take advantage of the characteristics peculiar to sponge iron. Whether its influence in the near future will be small or great cannot be predicted, but certainly sponge iron is a material that will affect future steelmaking practice.

In conclusion your attention is directed to the contribution that has been made by the War Metallurgy Committee, appraised as follows in an editorial by E. F. Cone in March 1945 *Metals and Alloys*: "More has been achieved (during the short life of this committee) than during 10 to 20 years under ordinary conditions. Never has there been a more productive and cooperative metallurgical engineering accomplishment." If some arrangement can be made to continue the research, it will be a change born in wartime that will vastly affect steelmaking practice. ☐

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Acid Electric Process for Steel Castings

ANY DISCUSSION of the advancement in foundry metallurgy — especially the melting of electric steel in the acid lined furnace — must give credit to the combined efforts of individuals and groups such as the Electric Metal Makers' Guild, the Electric Furnace Committee of the A.I.M.E., the American Foundrymen's Association and the Steel Founders' Society of America. When the war became imminent in 1940, greater tonnages of acid electric steel were needed, yet a minimum number of new installations could be expected. The general overall quality level was clearly subject to improvement. This newly created demand for acid electric steel prompted a change of attitude among acid electric producers which has resulted in the interchange of operating practices with a corresponding improvement in both quality and quantity.

It is well known that acid electric furnaces are primarily used in foundries. Their capacities ordinarily range from 3 to 5 tons of hot metal. In other words, they are small furnaces. In order to train the melters and operators needed for the increased tonnages, melting practices obviously had to be standardized for most efficient operation. While practices vary from one shop to another, modern procedures are basically similar and can be briefly covered by a general review. This will now be attempted.

Furnace — Speedy production of high quality metal is essential to normal foundry operation. The furnace, which is the working tool of the melter, should be properly designed; it should be

rugged yet well maintained for controlled operations. Practically all of the acid furnaces use a cold charge — hence speedy melting is essential. Low powered, slow and outmoded furnaces, or poorly maintained are controls, tend for high power consumption as well as increased labor costs of operation.

Modern acid arc furnaces are of the three-phase type with round shells, fitted with water coolers around the electrode clamps, electrode cooler rings, doors, and often the roof ring is also water cooled. These designed cooling fixtures add to the performance and life of refractories; however, excessive cooling results in a consumption of an extra number of kilowatt-hours. Practically all furnaces now have removable roofs for top-charging with a bucket, which saves time and labor over the old style laborious hand-charging methods. This feature minimizes radiation losses during the shorter time required for charging which again favors a low kw-hr. per ton. The tilting mechanism of the modern furnace permits a greater angle of movement for complete drainage as well as a reversing position — all of which permits the most satisfactory type of repairs to the lining between heats.

Many of the more modern installations are powered with over-capacity air (or water) cooled transformers. The kva. capacity per sq.ft. of bath area is often as high as 100, which is greater than used for basic arc furnaces, but contributes toward the speed of melting considered essential in the foundry industry. These new installations offer the melter a choice of several voltages, varying from about 250 to 90. Current conductors, bus bars, and other electrical fixtures are also extra heavy, since water cooling of these parts on the smaller furnaces is not essential. Considerable attention has been given by designers to the transformer and electrical parts, in an effort to minimize resistance, reactance and hysteresis losses.

Electrodes may be either graphite or carbon, but on the smaller furnaces graphite seem to be preferred for their increased strength. Electrode controls, drives, mechanical alignment and other modern features have contributed toward speed

and efficiency of operations. The smooth running of the furnace depends upon sensitive, quick-acting regulators for positioning and maintaining the correct arc length.

With proper electrical and mechanical equipment as outlined briefly above, speed and maximum efficiency may be expected. Current consumptions of less than 500 kw-hr. per ton are not uncommon, with continuous operation and high tapping temperatures. Electrical capacities capable of overload are desirable, as mentioned; however, there are optimum values of current (arc) input. Excessive power input can actually result in slower melting, with increased maintenance costs of electrode clamps, bus bars, and refractories, but these conditions are controllable by the melter, although not always understood.

Refractories—The acid furnace, by virtue of the name, is lined with acid or neutral refractories. Silica brick is still most widely used and from a cost viewpoint is highly desirable. Silica refractories are subject to spalling and, with intermittent operation, the life is low. In some plants, particularly where gas is cheap, spalling is prevented during shutdowns by maintaining the inner refractories at about 1200° F.; this greatly improves the life of silica refractories. A superior silica brick—which is a refined siliceous product of higher refractory quality—has been introduced and has given better service than the conventional brick. Super-duty, high alumina fireclay bricks have also been used as well as sillimanite brick in roof construction or in areas which are subject to excessive heat or spalling, with good results. Better low-cost refractories would be very desirable. Patching of the lining between heats is still being done by hand so that much patching material is misplaced and wasted. A good patching gun is needed and is now in the phase of development.

Charging

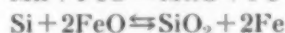
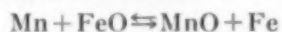
Modern top charge electric furnaces may have a 10-min. interval between power-off and power-on. If desirable and compact scrap is available, the entire charge can be made at one time; if not, "back charging" is necessary. Obviously, since the phosphorus and sulphur cannot be eliminated by the acid process, these and any other undesirable elements must be below specification requirements in the material charged.

Melting—Scrap should be placed in the charging bucket with the view that melting should proceed without interruption. Heavy scrap that would cause electrode breakage or delays should therefore be placed on the bottom with lighter

scrap on the top. Unwieldy, protruding shapes which cause bridging are not desirable and should be avoided. It is often better to pay more to prepare the scrap than to be troubled with costly delays, electrode failures, and other operational problems due to undesirable charge.

With the use of higher arc voltages, a larger hole is bored through the scrap and a larger pool of molten metal forms in the bottom of the furnace. For best melting procedure the electrodes should form a substantial molten pool of metal so that melting continues from this pool upward. This protects the sidewalls and roof from the high voltage, long flaring arc. Because the melting period in acid arc furnaces is short (often one hour or less), ore and limestone, if used, are usually added either with the charge or as soon as a molten pool is formed. This produces a thin slag, with better electrical conductivity for smoother arc operation. Ore in the early stages is also beneficial in starting oxidation and the fluid movement of a slag with low melting point. Melting therefore proceeds at a more rapid pace.

Oxidation—According to best known practices, oxidation of the melt is highly desirable for quality steels. This proceeds according to the following fundamental reactions:



In order that these reactions work to the desired degree, quantitative measurement of the free oxygen content is necessary. Recently several methods have been proposed for this measurement, but most of these check tests have been abandoned because of the time involved. Color of the slag has been a qualitative measurement for years, but now the viscosity can be measured with a reasonable degree of accuracy, with an indication of free oxygen content of both slag and metal for the temperature involved.

Slag viscosity is best measured by the method suggested by C. H. Herty wherein a spoonful of molten slag is poured into a 3-in. funnel leading to a ¼-in. horizontal hole, central in a 1¾-in. split cast iron mold. The distance the slag runs into this hole is a measure of its viscosity. For example, a thick, heavy or viscous slag may flow only 1 in.; a fluid, watery slag 11 in.

Such viscosity measurements closely predict the silica content of an acid slag, and give a less accurate (but useful) prediction of the iron oxide content. As the viscosity measurement rises, the FeO in the slag also goes up. Since the FeO in the slag tends to be in equilibrium with the FeO dissolved in the steel, a useful rule can be worked out by the melter for the conditions existing in his practice.



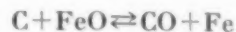
While the melter is primarily concerned with the metal, his metal is covered with the slag, and if time permits, the metal will become in chemical equilibrium with the slag. Slag control therefore appears to be the best indication of bath conditions at the present time.

Oxidation of silicon and manganese should continue until the silicon is well below 0.10% and manganese below 0.15%. Of course, excessive oxidation is not desirable and should be avoided. Dirty steel, off-analysis steel, and excessive lining corrosion usually follow over-oxidation. Neither is a dead melt (or under-oxidation) desirable, as off-analysis and poor quality steel with a high gas content will probably result.

As melting proceeds and is completed, the arc voltages should be reduced so that the lining will not be severely cut away by long flaring arcs. If this occurs, a thick viscous slag is built up from silica dripping from walls and roof; oxidation of silicon and manganese in the scrap then requires additional FeO with a resulting bulky quantity of

slag. Slag volume, for consistent and controllable operations, should remain nearly constant from heat to heat. The proportion of the slag weight to the metal is most important and must be taken into account for adjustment and calculation of alloys, because "as the slag goes, so goes the heat".

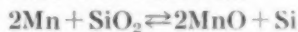
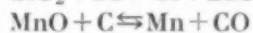
Under normal conditions, the temperature quickly increases so the carbon boil will take place if sufficient oxygen is present for reaction. Thus:



This reaction requires considerable heat input and does not take place until the bath attains a high temperature. Furthermore, sufficient oxygen should be available in solution for bath reactions. With rapid heat input, and available FeO for reaction, the carbon boil proceeds with great intensity, reducing the carbon of the bath often five points per minute. Adjustments of FeO of the bath or slag at this time are very important for consistent and well controlled practices.

Some melters prefer to "block" the bath, or catch the carbon on the way down. The preferred present practice is probably to add only enough FeO to carry the carbon bath to the desired state, so the bath and slag reach equilibrium at the temperature involved.

When the carbon reaction is completed, the bath temperature is usually well above 3000° F. If further boiling occurs with a heavy power input, silicon and manganese can easily be reduced from the slag by the following reactions:



These reactions take place easily in the acid electric furnace on account of the high temperatures commonly attained. (Often a 3200° F. tapping temperature is essential.) When furnace temperatures exceed 3000° F., silicon reduction by carbon and manganese becomes more difficult to prevent as time goes on, since the oxygen content of both bath and slag is decreasing continuously at high temperatures. This reduction of silica to silicon can be retarded by the judicious use of basic materials such as ore and lime, but as time and temperature continue to increase the last three reactions continue in a rapid cycle.

The above reactions have been widely publicized and are discussed at length in many techni-

cal articles. Technical details of operations are too lengthy to discuss. Let it suffice to say that through the medium of slag control, melting practices for acid electric steels have become standardized with resulting improvement of quality and quantity.

Deoxidation—The proper means for deoxidation and alloy adjustment still remains a controversial subject. In general, procedures favor the additions being made to the furnace rather than in the ladle. In order to avoid appreciable reductions of silicon and manganese from the slag, typical finishing slags before silicon and manganese additions may contain about 24% FeO (or about 46% total bases), and about 56% silica. Final or ladle slags may change in their proportions of basic constituents—such as an increase of MnO with a reduction of FeO—but the total of basic oxides in a normal slag will not change appreciably. This is of course dependent upon the melter. He must allow reactions, as heretofore stated, to run to completion so that slag and bath have reached a normal state of equilibrium at the temperatures involved.

These reactions, or the chemistry of steel making, seem now to be better understood by melters and many operators. If these reactions are not allowed to run their course the melter seems to work against the fundamental laws of physical chemistry, with the result that the heat has poor and uncontrollable qualities. The general improvement in quality of acid steels in recent years seems to be definitely related to furnace operations in accordance with the laws of physical chemistry, and the adjustment of furnace conditions for the proper reactions by the judicious use of acids or bases.

Teeming, or pouring the heat from the furnace to the ladle, is now generally done so that the metal enters the ladle first. This is usually accomplished by using a small tap hole, often fitted with a replaceable tile. A fast tilting movement quickly raises the slag level above the tap hole and holds it back in the furnace while the metal runs out underneath. This practice allows the positive addition of aluminum to the ladle of metal without the interference of slag, which drains with the final portions of metal. Grain size of acid steels, with 0.20 to 0.30% carbon and the usual 2 to 3 lb. of aluminum per ton, averages about 4 to 6.

Since the bulk of acid electric steel is made for castings, very hot metal is often required for sufficient fluidity to run the smaller castings. Tapping temperatures up to 3200° F. are then employed, which require highly refractory ladle linings. These ladles are usually lined with sili-

ceous material such as ganister with a minimum of bonding materials, rammed into place as a monolithic lining. With these extremely high pouring temperatures, teapot or lip pour ladles are usually employed.

With lower pouring temperatures, bottom pour ladles can be successfully used. These ladles do not present the same refractory problems, since temperatures are usually below 3050° F., even down to 2750° F., as measured by optical pyrometer. Fireclay brick ladle linings are generally satisfactory for a reasonable life.

Pouring temperatures are equally as important for castings as for ingots. Optical temperature measurements, while only relative, are employed as control measures. Better and more sensitive methods would be desirable.

Centrifugal Casting

Since most of the acid electric steel is poured into molds for castings, it may be well to inject a statement on the centrifugal casting process.

Casting by horizontal centrifuging in the manufacture of pipe sections is relatively old, but now a vertical method employing a shaped mold is being used with excellent results. This method permits the casting of shapes that cannot be made by the static method, particularly in extremely light sections where centrifugal force rapidly injects the molten metal into the mold, or castings which by nature or design are hard to feed properly. Many castings, impossible to make by conventional methods, have been centrifuged with excellent results, for pouring temperatures, speed of pouring, and surface speeds are all controllable factors. There also is an opinion that centrifuging of molten metal improves the characteristics of the casting. This may indeed be true—but, if both centrifugal and static castings are equally sound, no differences in physical qualities are found.

In conclusion it may be restated that a great deal has been learned by the free interchange of data during the war. It is earnestly hoped that the open-door attitude will continue among melters so that acid electric steel practices will remain in the quality category as time goes by with its developments and further progress.

Acid electric melting has many advantages in temperature and fluidity over any known processes for the steel foundry. Acid steel has a greater hardenability for equivalent composition. The acid furnace, when properly operated, is a most efficient, economical and speedy source of hot metal of excellent quality for carbon and low alloy steels.

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The Basic Electric Furnace for Steelmaking

BASIC electric furnace steel has been used almost exclusively for many years in the manufacture of special alloys and steels, including alloy toolsteels and die steels, heat and corrosion resisting steels such as stainless and other high alloys, steels for ball bearings and roller bearings, "aircraft grade" steels, certain automotive steels, high carbon steels, tank armor and other ordnance materials.

As early as 1940 the demands for alloy steel were steadily mounting. In the spring of 1942, the need for additional electric furnace steel for the tank program projected by the military authorities was over a million tons per year. Numerous plants equipped with electric furnaces were accordingly planned, approved and eventually built to meet the estimated needs.

The demand for electric furnace alloy steel for the war industries soon became so heavy and urgent and the completion of many of the new electric furnaces was so long delayed that it became necessary for many openhearth furnaces, then producing carbon steel, to go over to the production of alloy steel. This was done at the expense of carbon steel production, also in urgent and heavy demand. Diversion of much steel for the tank, armor plate and other programs from electric furnaces to openhearths, and other changes in specifications and demands, enabled the combined old and new electric furnace capacity to meet the various emergencies as they arose.

Since January 1, 1940, 3,421,040 tons of electric furnace alloy steel capacity has been

installed. Since that time, the total capacity and production in net tons, and the operating rates of electric furnaces (practically all operating on alloy, tool, stainless and special grades of steel) have been as shown in Table I.

Peak monthly production of electric furnace steel was in October 1943, when 414,327 net tons was made, equivalent to a rate of 4,971,924 tons per year.

According to the American Iron & Steel Institute's records, the total annual ingot capacity of the various processes used by

the industry as of January 1, 1945 is as follows:

Openhearth	84,181,590 net tons
Bessemer	5,874,000
Crucible	3,800
Electric	5,455,890
Total	95,515,280

(This includes 558,210 tons capacity of steel for castings made in foundries operated by companies producing steel ingots.)

Direct Arc Furnaces

The four types of direct arc furnaces which predominate today are the Heroult, Lectromelt, Swindell and Volta designs. As shown above, the phenomenal recent expansion in capacity was caused by the heavy demand for rich alloy steels and castings in the war effort. It is for such products that the arc furnace is particularly advantageous, because it affords very high temperatures, with heat available quickly and at will, and under fine regulation and control. It permits the treatment of metal under oxidizing, reducing or neutral slags, and through the control of slag enables the melter to control closely the analysis of his finished steel. Valuable elements can be recovered from scrap, ore or ferro-alloy additions, with good control of grain size and homogeneity in the product.

Electric arc furnaces are now installed in sizes ranging from 50 lb. to 100 tons. Recent figures show over 200 furnaces for producing ingots, and more than 500 furnaces for producing

Table I—Statistics on Electric Steel

YEAR OR DATE	OPERATING CAPACITY	PRODUCTION	OPERATING RATE
Jan. 1, 1940	1,882,620	1,700,006	90.3%
1941	2,930,803	2,869,256	97.9
1942	3,892,505	3,974,540	99.8
1943	4,745,677	4,589,070	96.7
1944	5,364,176	4,237,699	79.0
Jan., 1945	463,578	358,346	77.3
Feb., 1945	418,644	339,520	81.1
Mar., 1945	463,880	382,237	82.4
Apr., 1945	449,061	389,336	86.7

castings; the ingot producing furnaces are the larger, ranging from 10 ft. to 20 ft. inside shell diameter; the 100-ton capacity furnace has an elliptically shaped shell, 20x29 ft.

Current Characteristics

Alternating current arcs, playing between carbon or graphite electrodes and the metal bath below, are used almost exclusively in modern arc furnaces. With alternating current, the arc is extinguished at the end of each half-cycle; a certain instantaneous value of voltage must then be regained before the flow of current will start.

If the gap between the electrodes contains metal vapor—as it does in metal melting furnaces—the current may start practically simultaneously with the voltage. Much has been written on the subject of arc power factor and, of course, the ratio of the watts in an alternating current arc and the corresponding volt-amperes is theoretically less than unity. However, for practical purposes, the power factor in this class of service is practically unity. This refers to the arc alone. The power factor of the entire furnace circuit depends upon the electrical constants of the circuit.

The temperature of the arc is limited by the boiling of the material of the electrodes; with carbon electrodes, the arc temperature is approximately 3400° C. (6100° F.). A characteristic of the arc is the concentration of a large amount of power within a small volume of the furnace charge, giving a high temperature gradient to the charge with consequent high melting rate—an essential feature.

The inherent volt-ampere characteristic of an electric arc is such that energy in the arc is supplied in an unstable form. The condition for stability in an electric circuit is met only when the volt-ampere characteristic of the circuit shows an increase of voltage simultaneously with an increase in current. The stabilizing element for a three-phase arc furnace is usually provided

in the form of a reactor. The only objection to such reactance is its adverse effect on the power factor of the circuit. There is always, too, some resistance of the conductors in series with the arc; this is usually a negligible quantity but it is a stabilizing influence. There are other factors which affect arc stability, such as excessive gas pressures or free oxygen, but none of these are particularly troublesome in the ordinary operation of the electric arc furnace.

Automatic Control

Since changes in resistance occur rapidly and continually, the electrode control must be quick-acting at all times and in continuous operation. This is absolutely essential during the early part of the melt.

When, in the heat cycle, the power input to the furnace chamber is greater than the sum of the rate at which the charge will absorb heat and the rate at which heat is dissipated from the exterior of the furnace structure, the excess power will be expended in melting the lining and roof of the furnace. For this reason, and also because the arc resistance changes as the metal is melted, it early became evident that some sort of entirely automatic control was needed.

The simplicity of the control that has been devised by electrical engineers for arc furnaces is surprising. It has no complicated sequence of manual operations. Interlocking prevents the operator from getting into trouble, such as trying to operate the voltage tap changer when the circuit breaker is closed. Rheostats are provided so that he can adjust the load current, and the regulator will hold that current, but beyond that the really difficult part of the control is left entirely to the automatic regulator.

The automatic regulator operates the electrode motors which move the electrodes up and down, adjusting the gaps so that the current flowing in the arc in each phase will be balanced against the voltage from the electrode to the shell of the furnace. When this balance exists the electrode motors are at rest. At times it is necessary also to raise and lower all three electrodes simultaneously and this is done in a very simple and effective manner by a master control switch which can also be arranged to operate these motors at higher than normal speed.

Early arc furnace regulators were of the current operated, contact making, ammeter type and were never satisfactory. A major improvement was made many years ago when the balanced-beam regulator, actuated by current in the electrode and voltage from the electrode to the

furnace shell, was introduced. From that time nearly all regulators for arc furnaces have been made of this type. It is still being used, with continued good results.

Recently considerable interest has been aroused in rotating regulators, and several are in service. In all regulators of this type, the principle of balancing current on the electrode against voltage across the arc, which was established by the balanced-beam regulator, has been combined with variable-voltage control of the electrode motors. The advantages of this type of regulator are:

1. Variable-voltage control of the motors provides a motor torque which is directly proportional to the average unbalance between current in the electrode and voltage across the arc. This gives a diminishing torque as the balance point is approached.

2. Few interruptions of the arc occur during the melt-down.

3. When maximum unbalance occurs, as in short circuits, the maximum permissible voltage can be applied to the armature of the electrode motor, causing a high speed for withdrawing the electrode and lengthening the arc.

4. Controlling the input regulates the amount of heat in such a manner that no more heat is provided than the charge can absorb plus that radiated through the exterior of the furnace structure. This leaves a minimum excess power to be expended in melting the lining and the roof of the furnace, and results in a substantial saving in refractories.

5. Total time in melt-down is decreased, due to the sensitive control of the electrodes.

6. There is a saving of electrodes on the melt-down.

Electric furnace production of 99.8% of capacity throughout the whole year of 1942 is proof that development and progress in furnace design and in operating methods are balanced by progress in the design of electrical equipment and the power supply. However, none of the above improvements will bear fruit if the operator has not skill enough to use and maintain them. An appreciation by the operator of the electrical details involved will aid immeasurably in the economy and the efficiency of operation.

Charging Scrap

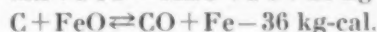
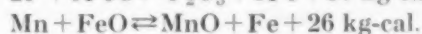
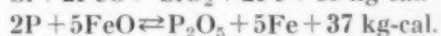
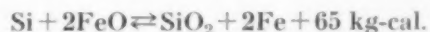
The method of charging cold scrap to an arc furnace varies with the type and the degree of subdivision of the scrap. For instance, the amount of scrap in the form of roll turnings that can be charged initially will rarely be sufficient

to give the weight of molten metal desired, so that additional quantities must be added as the metal in the furnace melts. This affects adversely both the energy consumption and the electrode consumption. The question of the proper method of charging cold scrap is one that should receive a great deal of attention in the operation of a three-phase arc furnace. Frequently, poor performance during the melt-down period can be directly attributed to improper placement of the cold scrap in the charge.

Chemistry of Basic Electric Steelmaking

The essential chemical reactions encountered in basic arc furnace practice, even though dissimilar from those obtaining in the openhearth, have long been known and partly understood. Some considerations of basic practice may, however, be better understood in the light of recent knowledge and research, and, with this in mind, a brief review of this subject is in order.

Oxidizing Conditions — Under an oxidizing slag, silicon, manganese, phosphorus and carbon are eliminated by reaction with ore, mill scale, or oxide on the scrap. However, contrary to openhearth practice, there is very little oxidation by the furnace atmosphere; this, of course, will improve the yield. The order in which these elements are oxidized, and the rapidity of their elimination, depend upon the relative heats as shown by the expressions which represent the thermochemical equilibria, or production of heat in kg-cal. from a mole-kilogram of the reactants



The broad statement made above only holds good if no side reactions come into play, and if the products of the reactions are not gaseous. (It should be remembered that exothermic reactions are favored by a low temperature, while endothermic reactions take place more rapidly at high temperature, which can reverse the above order of elimination.) Silicon is eliminated most rapidly, next being manganese and chromium, the latter behaving similarly to manganese.

Phosphorus should be eliminated before manganese and carbon in accordance with its thermal evolution, but the P_2O_5 formed will combine with FeO to give ferrous phosphate, which is unstable in the presence of carbon. However, P_2O_5 will form a stable phosphate with CaO if this is present in uncombined state in the slag. The slag must, therefore, contain an excess of

free lime, and must also be oxidizing and fluid, before phosphorus can be eliminated in preference to carbon. This happens more often in arc furnace practice than in the openhearth, as the higher slag temperature permits a more highly calcareous slag of reasonable fluidity. Phosphorus removal is, therefore, governed by the basicity of the slag, other conditions being equal.

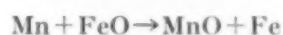
Carbon and phosphorus elimination is, however, more or less concurrent, although charges may be worked down by eliminating phosphorus before carbon. There is no advantage to be gained by this latter procedure, as simultaneous dephosphorization and decarburization is a more rapid process by reason of the agitation of the bath which accompanies the evolution of CO. The heat given up by the phosphorus reaction balances the heat absorbed by the carbon reaction, thus making for temperature stability.

Decarburization of the bath is more or less independent of thermal considerations since the product of the reaction is gaseous and escapes from the sphere of the reaction. Theoretically it is limited by the solution pressure of CO in molten steel, but this is comparatively low. The

reaction, being endothermic, is favored by high temperature, and if temperature is high enough the rate of carbon elimination will be such that there is a considerable quantity of phosphorus left in the steel when the carbon is gone; at the same time the bath will be over-oxidized.

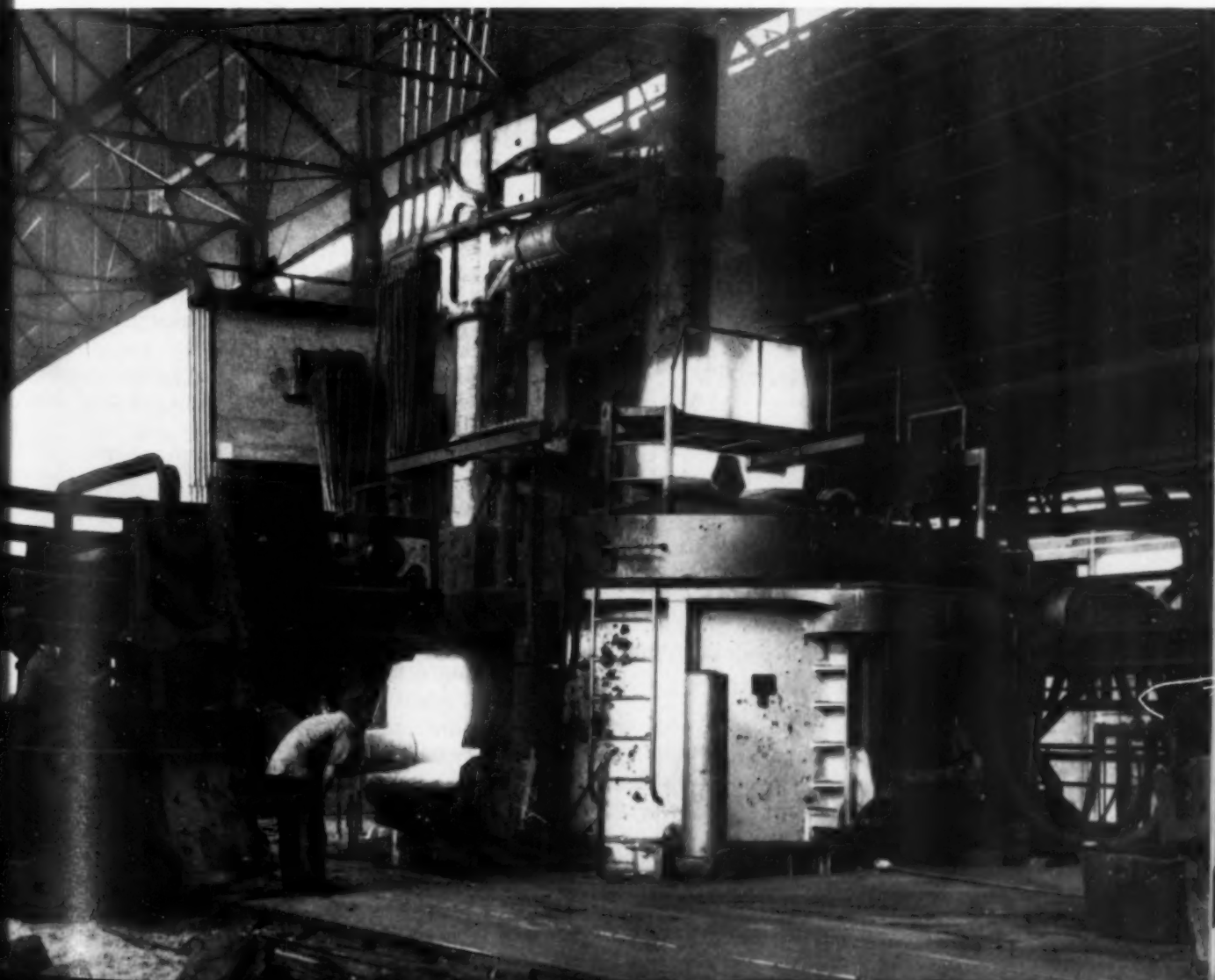
It is very easy to build up the temperature in the arc furnace when melting is complete, and this should be avoided by lowering the power input. Phosphorus elimination, contrary to carbon elimination, is favored by a *low* prevailing temperature; consequently the charge should be worked in such a way that a considerable amount is removed before the boil starts and the temperature starts climbing.

The use of manganese ore is recommended. This will maintain a high MnO content in the slag, and the oxidation of phosphorus and carbon will then release metallic manganese which, in accordance with the following reaction, insures a low FeO content in the steel:



Some sulphur is eliminated during the oxidizing period, but its removal is uncertain and

Views in This Article Were Photographed in Electric Furnace Dept. of Bethlehem Steel Co.



not thoroughly understood. Normally up to one-quarter of the sulphur contained in the scrap is recorded up to the moment of slagging. Some of this is held in the slag as MnS or CaS, but the greater part is probably oxidized to SO₂ gas.

The importance of skimming off all traces of oxidizing slag will be evident, as it destroys the effects of the reducing conditions to be established later, and if any is left the phosphorus in it reverts to the steel. (The calcium phosphate will be decomposed by the silicon or calcium carbide in the deoxidizing slag or by the alloy additions, resulting in a phosphorus pick-up.)

Deoxidizing Slag

Depending upon the chemical composition of the metal being made, there are various types of finishing slags, namely:

1. Calcium carbide.
2. Lime-silica-carbon.
3. Lime-silicon-carbon.
4. Lime-silicon.
5. Lime-aluminum.
6. Lime-silicon-zirconium.
7. Lime-calcium-silicon.

Slags No. 1, 2 and 3 are used for the various types of S.A.E. steels, depending upon their composition.

Slags No. 4 to 7 are used for stainless steels, heat resisting steels and alloys.

The following reactions occur during the desulphurization and deoxidation period, which is the essential feature of the basic electric process:

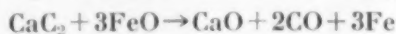
The lime is partly held in solution by spar (CaF₂) and partly converted to calcium silicates by SiO₂ formed by the reaction between ferro-silicon and the oxygen dissolved in the steel. Some silica (SiO₂) also enters the slag through "drippings" from the silica brick roof. Ferro-silicon, if present in the slag, reduces the oxides in accordance with the familiar reaction:



Some steelmakers prefer to deoxidize to the greatest possible extent by means of the carbon in the slag, the reaction being



Also, calcium carbide is continuously formed in the region of the electrodes and is almost immediately consumed in the following manner:



It is not until the slag becomes very low in oxides that the calcium carbide remains as a constituent of the slag. This condition will mean that the velocity of migration of oxides from the

bath is slower than the rate at which CaC₂ is being formed. Its presence need not of necessity denote perfect deoxidation throughout the melt.

Calcium carbide will never completely deoxidize steel, but it possesses the virtue of a reagent that does not leave behind any solid inclusions. The reaction takes place at the plane of contact, slag-to-metal, and CaO will be formed, eliminating oxygen from the bath, until the reaction is limited by the solubility of CO in molten steel at the temperature of working. If the steel were cast under these conditions, the CO, as such, would be dissolved in the steel. (Oxygen is dissolved in the steel as FeO, but it is expressed in this way to conform with other work bearing on the subject.)

This "carbide" slag is strongly basic, made by adding lime, pulverized carbon (graphite, petroleum coke, or anthracite coal), fluorspar, and silica sand or pulverized ferrosilicon. Some of the carbon is taken up by the steel, thereby increasing its carbon content. The chief purpose of the carbon, however, is to react with the lime to form calcium carbide, which is the important constituent of this slag. This slag has as its dual function the further reduction of oxide and elimination of the sulphur. Samples of this second slag, taken intermittently, become gradually lighter in color and, after some time, will liberate acetylene gas when dipped in water. When this point has been reached, the indication is that the bath is deoxidized and desulphurized. The various reactions taking place to attain the deoxidized and desulphurized condition follow.

The addition of pulverized carbon to the slag returns manganese to the bath:

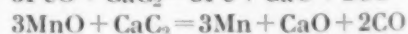
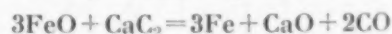


and the carbon monoxide mixes with the gases in the furnace and assists in maintaining a reducing atmosphere.

Calcium carbide is formed in the slag by the simple reaction between the pulverized carbon and lime under the heat of the arc:



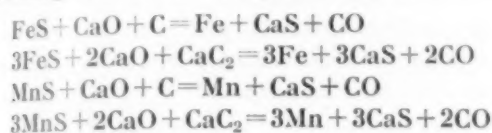
When this occurs, further deoxidation takes place. Two equations represent the reactions:



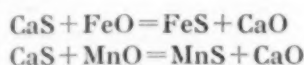
This means that the carbon is being consumed and more must be added to the slag from time to time until the lime is liberated by the above reactions; the slag must be kept strongly basic and reducing throughout.

Sulphur occurs in the bath either as iron sulphide (FeS) or as manganese sulphide (MnS).

Not until deoxidation has been completed does the combined sulphur react with calcium carbide because, in the presence of oxide, the two reactions just written will take place preferentially. Sulphur is eliminated as calcium sulphide CaS according to the following reactions:



If deoxidation is not completed, the CaS reverts to CaO:



All the other reactions are no doubt occurring simultaneously until all oxide is removed. It is then that the sulphur is eliminated as CaS, which is absorbed by the slag.

The requirements are a neutral or reducing atmosphere in the furnace and the melting of a strongly basic slag. In order to make these basic slags easily fusible, fluorspar and quartz (in the form of sand) are added.

In reactions of the type of

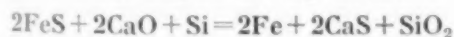


carbon is required, and the reaction is benefited by the favorable influence of the electrodes. Carbon must be added to the bath, and for this reason the process is not used for the production of low carbon steels. In melting very soft steels, one must either take into account a certain carbonization of the bath, and later remove the carbon, or else be satisfied with a less complete desulphurization. Even if the carbon is only thrown on the slag covering from time to time, a certain absorption by the bath cannot be avoided.

Another desulphurization process follows the chemical reaction between silicon and sulphur, whereby SiS is produced and escapes as gas.



If, at the same time, a lime-carrying slag is formed on the metal bath, further desulphurization occurs according to the equation:



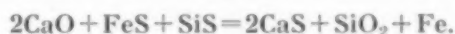
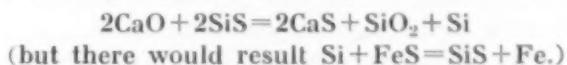
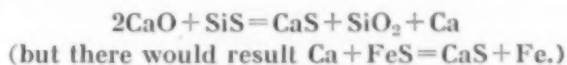
The CaS is removed in the slag. It is interesting to know that both reactions take place almost quantitatively so that scarcely more than the theoretical amount of ferrosilicon must be added to the bath. A low silicon steel can therefore be produced if desired. The reaction gives a very fluid slag because the proportion of silica to lime is increased.

Moreover, fluorspar is also an equally good

desulphurizing agent when ferrosilicon is used, according to the equation:



Many theoretical reactions have been suggested to account for the desulphurization by silicon in the basic electric furnace. A few of these are given below. The first three depend on the use of burned lime.



The SiS in all these equations is thought of as being produced by



They also all represent the same reaction, namely:

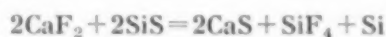


The slag will be made thinly liquid by the silica produced and, in this reaction, sulphur requires one-half a mole of silicon.

Equations involving the use of fluorspar are as follows:



(The SiS is produced by the equation $\text{FeS} + \text{Si} = \text{Fe} + \text{SiS}$.)



This silicon liberated would decompose more FeS.

Both reactions, therefore, mean the same:



When this reaction occurs the slag becomes basic, that is, thicker. By this reaction one mole of sulphur also requires one-half mole of silicon.

A résumé of these equations boils down to



Note that these reactions are the same except that in the first the oxide of calcium, and in the other fluoride of calcium, is the reagent; both processes require the same amount of silicon.

Desulphurization by the alternate reaction between FeO and FeS and the formation of SO₂ cannot be carried to completion in liquid metal. For this reason it is only suitable for heats where complete desulphurization is not required.

Spectrographic Analyses

One of the many factors governing the time required for completing a heat of steel is the speed with which tests and analyses can be

made after the melt-down and during the refining period. The quicker the tests and analyses can be completed, the shorter the heat time, and the greater the output per furnace.

Spectrographic analyses of samples taken during the refining of a heat (except for carbon, phosphorus and sulphur) are reported in less than 15 min. Many single determinations are reported in 9 min., while during peak-load conditions the analyses of eight elements may take as long as 25 min. Spectrographic results have been found as accurate as those obtained by the old standard methods of chemical analysis.

For some steels, and for certain elements and ranges, the spectrographic method has been found even more accurate than the chemical. This is true for silicon in complex steels, molybdenum in tungsten steels, tungsten below 1.00%, and for most elements present in concentrations below 0.20%.

At present the spectrographic laboratory at the Bethlehem steel plant is analyzing the following elements within the ranges given. Work is under way to extend the procedure to other elements and to expand the ranges.

Manganese	0.05% to 1.00%
Silicon	0.002 to 0.70
Molybdenum	0.002 to 6.50
Chromium	0.03 to 2.00
Nickel	0.01 to 3.50
Cobalt	0.03 to 0.30
Tungsten	0.05 to 1.00
Vanadium	0.005 to 1.50
Copper	0.04 to 0.50
Aluminum	0.004 to 2.00
Titanium	0.005 to 0.10
Tin	0.003 to 0.10
Boron	0.001 to 0.05

Satisfactory spectrographs, microphotometers, and electrical sources are made by several manufacturers.

Side Walls

Paradoxically, basic furnace side walls may be constructed of either basic brick or silica brick. Basic brick, despite its relatively higher cost, is displacing more and more silica brick.

One type that finds extensive use is the so-called metal-encased or metal-case brick. A common type was made by filling short lengths of scrap boiler tubes with ground magnesite. These "brick", of circular cross-section, were laid up into furnace walls with substantial amounts of ground chrome ore or magnesite to fill the interstices. Metal containers of rectangular cross-section were also used. For electric furnaces these containers were formed into key shapes for turning the circular walls.

One difficulty with metal-case brick arose from the fact that the magnesite within the container was not dense, since it could not be pressed together in the container under the highest pressures. To overcome this it has been suggested that the refractory be first pressed into brick form without the metal container; this is done in a conventional press under relatively high pressure. The metal case is fabricated separately from sheet steel, to form an enclosure for bottom and sides. The preformed brick are fitted into this case and the composite is ready for use.

It has also been suggested to use a hydraulic press to obtain high molding pressure. The brick is molded into form within the steel envelope in one operation. To do this a piece of 16-gage sheet steel, formed into a U-shape with external dimensions equal to the desired brick size, is placed in the brick mold. Then the refractory mix is filled into the mold. A forming pressure is applied slowly from a top plunger that closes the mold. The plunger is magnetized and its under surface carries a piece of sheet steel of proper size to complete the four-sided envelope. When full pressure is applied to the plunger, the brick is formed and the steel envelope is firmly attached at the same time. A basic refractory containing more than 20% chrome ore in the mixture (and even as much as 75% chrome ore) has been used with considerable success for special furnace linings.

Roofs

For constructing basic furnace roofs, silica brick are most commonly used, as they have the unquestioned advantage of being cheap and readily available. They also have excellent strength up to their fusion point. The principal difficulty with silica brick is their relative fusibility. Average silica brick, with the normal amount of impurities, melts at about 3050° F. (or cone No. 31). Thus the operating temperature of the roof comes very close to the melting point of the refractory itself. For this reason it is important that nothing but the best grades of silica brick be used in the roof. The brick should be accurate to dimensions, fully burned, dense and well bonded. Pennsylvania ganister brick would normally contain about 96% SiO₂, 1.5 to 2% CaO, and 1.00% Al₂O₃.

Silica brick have a marked tendency to spall under certain operating conditions (temperature fluctuations). The cristobalite phase, which constitutes a preponderant part of the brick, has an unusually high thermal expansion at low tem-

temperatures, and low temperature spalling is therefore serious. Silica brick do not spall at higher temperatures.

In heating from room temperature to 575° F. (300° C.) cristobalite may expand 1.3% or more. By further heating to 1100° F. (600° C.) it will expand another 0.3%. Silica brick do not spall with temperature fluctuations above 1100° F., but with fast heating below 600° F. they can be rapidly destroyed. Special precautions must be taken during intermittent operations, to prevent spalling below the maximum expansion point.

Super-duty fireclay brick, containing from 40 to 50% alumina, are sometimes used for roof construction on intermittent furnaces. These brick resist spalling excellently. They have a pyrometric cone equivalent of 33 to 34, corresponding to 3100 to 3200° F., which is more than 100° above silica brick. This increased refractoriness is helpful, but on account of excessive shrinkage above 2800° F. they are not suitable for basic arc furnace operations when temperatures run above 3100° F.

Brick with 50 to 60% alumina are more stable than those containing 40 to 50%. Their increased refractoriness is also helpful, but the brick tend to shrink badly at about 3000° F. Consequently the most satisfactory of the higher alumina refractories are of the sillimanite type, ranging from 60 to 65% Al_2O_3 . These brick are made from calcined Indian kyanite. They have a pyrometric cone equivalent of cone 37, are stable and do not shrink seriously even at 3100° F. (Brick made from domestic calcined kyanite, so far as our experience goes, are not stable and shrink at the high operating temperatures of the basic arc furnaces.)

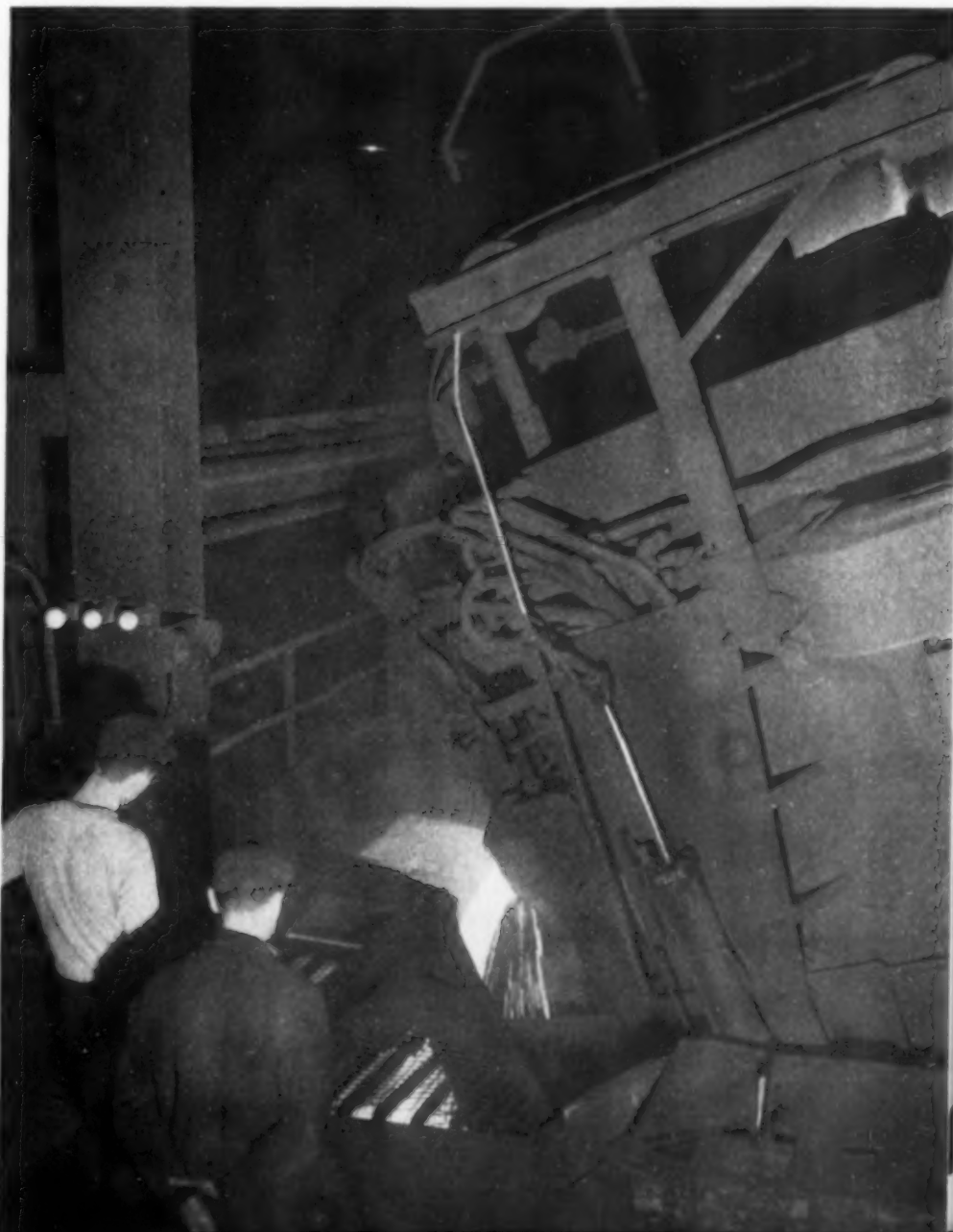
Rammed Bottoms

Rammed bottoms of moderately high magnesia content, properly installed, have given good service in our plant. The material is shipped in 100-lb. bags as dry clinker, a mixture of fine

and coarse particles. It is mixed with water only at the furnace, to a consistency of damp molding sand, just before putting into the furnace.

The usual amount of water needed is $\frac{3}{4}$ gal. (6 lb.) to 100 lb. of mixture. Too much water must be avoided; a soupy mixture will not dry thoroughly, but forms a spongy mass that will not ram into a hard bottom, or make a sound patch. The only remedy, if such material gets into the furnace, is to remove it and substitute a drier mixture. It may also hydrate badly.

On the other hand, too dry a mixture cannot be rammed to the desirable maximum density and strength. The amount of mixture to be prepared at one time depends on the speed of ramming. It rams very easily, as it does not creep under the hammer, and it is possible to put in upward of 1000 lb. per hr. per rammer. The mixture should not be permitted to stand for more than 15 min. before ramming, so large quantities should not be prepared in advance.



The most satisfactory rammer is a molder's air hammer with 6 to 7-in. stroke and 3-in. head, operated at 80 to 100 lb. of air pressure.

To prepare the furnace for a new bottom the brickwork is first cleaned of adhering slag and metal, all dust is blown completely off and the brick surfaces that will come in contact with the rammed material are scrubbed thoroughly either with plain water or — much better — a 4 to 1 mixture of water and sodium silicate. This prevents the brick from absorbing moisture from the MgO mix as it is rammed and set in place. The contour of the brick sub-hearth should be the same as that desired for the contemplated hearth, and there should be a minimum of 5 in. of the MgO mixture at all points.

In small furnaces, the mixture may be rammed over the entire hearth at one time. The determining factor is: Do not apply more magnesia mixture than can be properly rammed before it dries out. In large hearths, the bottom should be rammed in sections, using a bracing of wooden forms to provide a solid frame against which to ram. On the removal of a form, the edge of the rammed material next to the form must be well roughened to insure a good bond with the next section to be rammed. The first layer is spread loosely to a thickness of about 5 in. and reduced to about 3 in. with a hard surface after ramming. Before each layer is started the foundation surface must be scratched deeply to give a perfect bond and to prevent laminations.

After the bottom is in, lump coke is added to fill the furnace level to the door sill. Heat is then applied to the central area of the coke, under the electrodes, with an oil or gas burner for approximately 5 hr., until the coke is red hot. The high voltage is then turned on. After approximately 2 to 5 min., the voltage is changed to low (125 volts), corresponding to about 12,000 amp. with a power factor of 75 to 78. Heating is continued until the temperature reaches approximately 2600° F.; this requires about 24 hr.

After the furnace has been held at this temperature for 8 to 10 hr. it is tilted and all ash and coke removed. Consideration must now be given to the other refractories in the furnace. If a silica roof is used, care should be taken during the burning in of the bottom to prevent the roof from getting so hot it drips onto the hearth; if it does start to drip, the power must be shut off temporarily.

A preliminary wash heat of high carbon steel, 1.00 to 1.30% carbon, without slag-off, is made before the furnace is placed in service.

The quantity of magnesia mixture for a new bottom in a 50-ton furnace of 18-ft. shell diameter is approximately 26,600 lb. It contains about 200 gallons (or 1600 lb.) of water, and it will require about 45,000 kw-hr. for burning in.

Bottom life can vary widely. The most important factor is, of course, the quality of materials and manner used in making the bottom, the types of steel made, and the skill of the operator as manifested in the judicious use of power, and the selection and placing of charge and slag materials. Bottoms of the type described have been used in making 3000 to 5000 heats (the tonnage of ingots depends upon the capacity of the furnace), all of which are double-slag heats of alloy steel, usually with a few of stainless type.

Door arches and jambs must be so designed that the brickwork is not damaged in charging. For long periods of continuous operation, magnesite linings are justified for the basic furnace. However, magnesite arches and jambs have poor structural strength and are a source of delay between heats because of their frequent need of repairs. Much of this may be avoided by installing water-cooled arches directly back of the door frame, to supplant one course of brickwork and to support the whole arch and jamb. They are very efficient when serviced adequately.

Increasing the size of door openings permits the use of larger charge boxes, and will speed up charging from 15 to 20%. This is important in the larger furnaces.

Liquid Metal Refining

It was early realized that the electric furnace was the most potent appliance in the hands of the metallurgist for the complete removal of sulphur and oxygen from the steel, and the only drawback lay in the relatively high expenditure on power for the production of intermediate grades of steel. This led to the development of the duplex and triplex processes, in which the metal is partially refined elsewhere before it is transferred to the electric furnace. From the standpoint of electrical costs, the high maximum demand charge is considerably reduced for a given output of steel, as only a low regular input is required for maintaining temperature during refining. (There is no melt-down stage.) The cost of current is further reduced by a high load and power factor, as little inherent reactance is required to palliate current surges, which are small with liquid charges.

The metal is brought from the converter or openhearth plant in ladles and is poured into the

electric furnace through a launder or a tilting ladle spout. Phosphorus is rarely a problem, as a basic converter or openhearth is invariably employed for the preliminary work, and silicon, manganese, carbon and phosphorus have already been eliminated before the metal reaches the electric furnace. Otherwise, dephosphorization would introduce difficulties and entail expenditure of time due to the necessity for slagging a large bath of metal.

In a plant in South Chicago a triplex process was worked. Pig was first blown in an acid converter, wherein silicon was completely eliminated, and manganese almost completely, while carbon was brought down to the region of 0.60%. Refining for the phosphorus and carbon was completed in a basic openhearth furnace, while the arc furnace served to desulphurize and finish the steel. In this way large outputs were possible, but the synchronization of the three processes presented very serious operating difficulties.

Some years ago large acid-lined arc furnaces were used in European plants for liquid metal, notably at Gutehoffnungshütte. They only served as heated receptacles for superheating and adding deoxidants, although some non-metallic inclusions were separated by allowing the metal to remain tranquil in the furnace before pouring. Basic-lined converters were used to do all the refining necessary. It was, in fact, an attempt to simulate the conditions obtaining in crucible practice; silicon was actually reduced from the acid lining. Various theories were propounded to explain the alleged high degree of deoxidation, but the process had so little to commend it that it was never widely applied.

The only really successful hot metal process is that employing a duplex system whereby basic openhearth or bessemer metal is put under a carbide slag in the arc furnace. Complete desulphurization ensues and, if the process is not unduly hastened for the sake of production, exceedingly gratifying results are obtained.

Furnaces for such a process are preferably 20 to 30 tons in capacity. However, recent installations are of 75 tons capacity, and the working substantially duplicates the reducing slag period in the cold-scrap process. Part of the lime is added simultaneously with the steel when the latter is being poured into the furnace, while the remainder is built up with the slag on the bath. If extremely pure pig iron is obtainable an acid converter may be employed; the basic arc furnace is then chiefly used for deoxidation. A plant working on this principle at Cogne, Italy is referred to by Giolitti in *Metal Progress* for January 1931. The liquid iron from the blast

furnace containing 4.50% carbon, 1.50% silica, 0.80% manganese, 0.03% phosphorus and 0.03% sulphur, is transferred to a mixer before blowing. The converter blast is stopped before all the carbon, silicon and manganese are eliminated, and the metal is then put into a 25 to 30-ton basic arc furnace. The time in the arc furnace is 1 to 2 hr. and the output of the plant is 300 tons per day.

Generally speaking, it has been found that difficulty of synchronizing operations and the cost of transferring molten metal almost equal the savings in melting costs. This has militated against the use of duplexing to the extent which at first appeared likely.

A number of installations made in this country during the past four years operate on various sequences of processes, such as

1. Bessemer converter blown metal to electric furnace.
2. Bessemer converter blown metal to tilting openhearth furnace, to electric furnace.
3. Tilting openhearth furnace to electric furnace.
4. Melt turnings (briquetted, loose or crushed) in a cupola, refine in electric furnace.
5. Cupola to bessemer converter and refine in electric furnace.

All of the above must be developed mechanically and metallurgically.

New Developments

Certain developments will be used more extensively in the basic arc furnace within the near future. For example:

1. Improvement in refractories for the larger sizes of furnaces.
2. Preparation of turnings to eliminate moisture and carbonaceous material.
3. Preparation of light scrap in briquette form.
4. Program control for regulation of power input on the melt-down.
5. Development of spectrographic analyses for preliminary tests of high alloys in the melt-down and during refining.
6. Improved metallurgical processes for rapid refining of some grades of steel of the lower alloy group.
7. The use of inert gas for regulating the furnace atmosphere for special grades of alloy steel.
8. The use of inert gases for flushing the metal in the ladle before casting.
9. Development of the immersion thermocouple to obtain accurate tapping and pouring temperatures.

Properties of Refractory Materials, Except Fireclay

Compiled by Stuart M. Phelps, and Copyrighted 1935 by American Refractories Institute, Technical Dept., Mellon Institute

MATERIAL (1)	COMPOSITION OF THE PURE MATERIAL		MELTING POINT	TRUE SPECIFIC GRAVITY	HARDNESS (MOH'S SCALE)	MEAN SPECIFIC HEAT (17)	THERMAL EXPANSION (Note 22)	THERMAL CONDUCTIVITY (2)		
	FORMULA	COMPOSITION %						At 1000° F.	At 1600° F.	At 2400° F.
Andalusite	$Al_2O_3 \cdot SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810° C. 3290° F.	3.20	7.5	0.168 (18)	6.2°			
Chromite	$FeO \cdot Cr_2O_3 \cdot (3)$	Cr_2O_3 68 FeO 32	2180° C. 3956° F.	4.5	5.5	0.22°	8.0°	10.0°	10.9°	12.1°
Corundum	Al_2O_3	Al_2O_3 100	2050° C. 3722° F.	4.0 (24)	9	0.304°	8.5	23.0°	26.5°	30.0°
Cyanite (Kyanite)	$Al_2O_3 \cdot SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810° C. 3290° F.	3.6 ±	4 to 7		4.9° (4)			
Diasporite (Diaspore) (5)	$Al_2O_3 \cdot H_2O$	Al_2O_3 85.1 H_2O 14.9	2050° C. 3722° F.	3.4 to 3.5	6.5 to 7	(Note 6)	6.5°			
Dolomite	$CaCO_3 \cdot MgCO_3$	CaO 30.4 MgO 21.9 CO_2 47.7	(Note 23)	2.81 to 2.95	3.5 to 4.0	0.222 (19)	14.0			
Dumortierite	$8Al_2O_3 \cdot 6SiO_2 \cdot B_2O_3 \cdot H_2O$	SiO_2 64.6 Al_2O_3 28.5 B_2O_3 5.5 H_2O 1.4	1810° C. 3290° F.	3.30	7		5.2°			
Forsterite	$2MgO \cdot SiO_2$	MgO 57.3 SiO_2 42.7	1910° C. 3470° F.	3.22	6 to 7	0.22 (19)	10.5°	11.1°	10.6°	10.3°
Graphite	C	C 100	>3000° C. >5432° F.	2.25	1 to 2	0.29	2.2			
Magnesia spinel	$MgO \cdot Al_2O_3$	MgO 28.2 Al_2O_3 71.8	2135° C. 3875° F.	3.6	8	0.257	8.5	12.2°	13.3°	14.5°
Mullite	$3Al_2O_3 \cdot 2SiO_2$	Al_2O_3 71.8 SiO_2 28.2	1810° C. 3290° F.	3.03		0.175 (20)	5.3 (7)			
Periclase (Magnesia) (8)	MgO	MgO 100	2800° C. 5072° F.	3.64 to 3.67	5.5 to 6.0	0.285	13.5°	19.5°	15.5°	13.0°
Quartz (9) (Quartzite)	SiO_2	Silica 100	1400° C. (10) 2552° F.	2.653	7	0.263°	32.6° (11) 4.6 (12)	8.8°	10.7°	13.3°
Silicon carbide	SiC	Si 70 C 30	2250° C. (13) 4082° F.	3.17 to 3.21	9 to 10	0.19 (14)	5.2 (15)	142°	110°	80°
Sillimanite	$Al_2O_3 \cdot SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810° C. 3290° F.	3.24	6.5 to 7.5	0.175				
Zircon (Zirconium silicate)	$ZrO_2 \cdot SiO_2$	ZrO_2 67.1 SiO_2 32.9	2550° C. 4622° F.	4.7	7.5	0.132 (21)	4.5			

- These properties refer to pure materials and not to commercial refractories which may differ because of impurities, bonding materials, and process of manufacture. The specific heat, thermal expansion and thermal conductivity data, however, may be used for engineering purposes and especially those marked with asterisk (*) which were obtained from commercial products.
- Thermal conductivity in B.t.u. per in., per hr., per sq.ft., per °F., averaged from the more reliable data on refractories.
- General chemical formula for chromite is $RO \cdot R_2O_3$. The RO oxide is usually FeO and may be replaced in part by MgO , while the R_2O_3 is mostly Cr_2O_3 , but may be replaced in part by Al_2O_3 and Fe_2O_3 .
- Indian.
- Commercial diaspore is composed of diaspore grains bonded with clay.
- Probably close to 0.26.
- Synthetic, pure.
- Magnesite is amorphous, or crystalline like periclase, depending upon the heat treatment it has received.
- Ganister is the commercial form for use in refractories, about 98% silica.
- Crystobalite is the stable form of silica above 1470° C., and has the melting point of 1713° C. (3115° F.).
- Value is for silica brick, mean expansion in range 20 to 300° C.
- Value is for quartz, mean expansion in range 300 to 1135° C.
- Dissociation temperature; oxidation may begin at 900° C. (1652° F.)
- Varies with temperature.
- This figure, and those for thermal conductivity, are for recrystallized material.
- Pure material sintered.
- For the range 20 to 1000° C. (68 to 1832° F.) unless noted.
- For the range 0 to 100° C.
- For the range 20 to 100° C.
- For the range 20 to 800° C.
- For the range 21 to 51° C.
- Values for the mean reversible thermal expansion per °C. times 10⁶, for the range 20 to 1000° C. unless noted.
- Dissociates at very high temperatures.

for the range 20 to 1000° C. unless noted. Dissociates at very high temperatures.

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50%

Fe Si

75%

Fe Si

Fe Si

85%

Fe Si

90%

Fe Si

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Ohio Ferro-Alloys Corporation
Canton, Ohio

Chicago Detroit Pittsburgh San Francisco Tacoma

DIECASTING DIGEST

VIII — Die Castings Replace Forgings, Sand Castings and Permanent Mold Castings

More and more non-ferrous alloy parts, formerly made by forging, sand casting or permanent mold casting, are now being die cast to satisfy demands for rapid production, dimensional accuracy and best possible performance. Back of this trend

are improvements in die casting machinery which have given engineers confidence to design and specify die castings.

In many plants, Lester-Phoenix die casting machines, equipped with high pressure pre-fill injection systems, are making

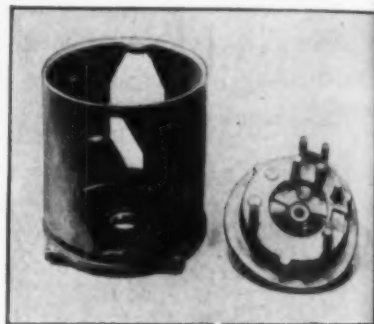
aluminum castings which, only yesterday were thought impossible to die cast. For instance, by die casting the three links shown below, Sperry Gyroscope Company saved weeks of time and obtained aluminum parts fully as satisfactory as those previously made by forging. Such parts are made by "slow-squeeze" injection which packs metal into the die at comparatively low speed, permitting escape of air ahead of the metal, and then applies

Converted to Die Casting:



... from forging

pressure (up to 33,000 psi) on the metal as it chills. This minimizes the formation of gas pockets and shrinkage voids (the causes of porosity in die castings) and produces sound die castings, with physical characteristics not otherwise obtainable.



... from sand casting.

The other two aluminum die cast parts shown are a chassis (left) and a bracket for a Sperry stabilizing unit. The die castings replaced sand castings; now the parts are made in a fraction of the former time, with most of the chassis machining eliminated and with the bracket cast to close tolerances.

DIE CASTING DATA

The casting technique to produce sound die castings is discussed in an article (now reprinted) by S. U. Siena, superintendent of the Sperry Gyroscope die casting department. Write today for your FREE copy. Lester-Phoenix, Inc., 2619 Church Avenue, Cleveland 13, Ohio.

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DIE CASTING MACHINES

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The "Gear-Housing" portrayed here is one of the many steel castings going into these "Bull-Dozers", requiring strength, rigidity, proper metal distribution and good appearance to win the admiration of the entire engineering profession.



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Electrical Machinery & Equipment
Elevator
Engine
Food Processing & Packing Plant
Foundry Machinery & Equipment
Gas Producer & Coke Oven
Gears
Heat Treating Furnace & Equipment
Hoist & Derrick
Iron & Steel Industries

Metallurgical Machinery
Mining Machinery & Equipment
Oil or Gas Field & Refinery
Ordnance
Overhead Crane & Charging Machine
Paper Mill
Printing Press
Pump
Railroad
Refractory, Brickyard & Ceramic
Refrigeration Machinery

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DETROIT, MICHIGAN

Detroit Steel Casting Company
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TOLEDO, OHIO

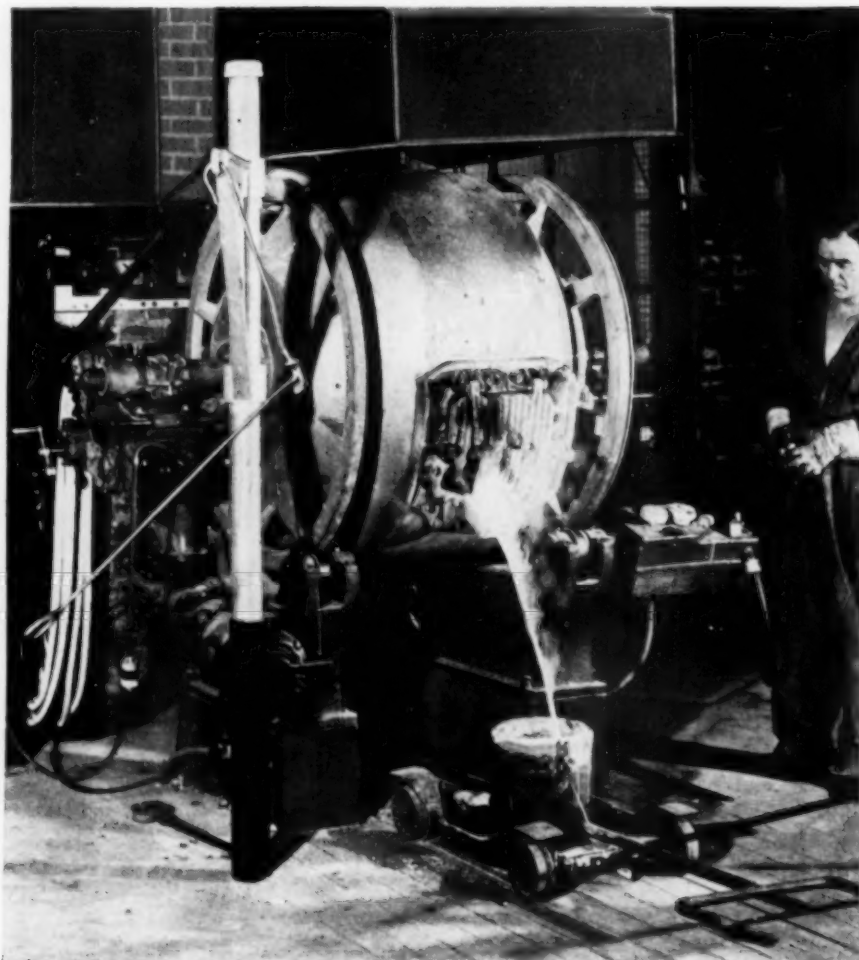
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40 minutes per heat with a Detroit Rocking Electric Furnace



700 lbs. every 40 minutes! That's the productive speed of a Detroit Rocking Electric Furnace which was clocked during a typical day's operation melting bronze for valve castings. Melting time was approximately 30 minutes; charging and pouring time approximately 10 minutes per heat. Over all average power consumption 275 Kw. Hrs. per ton. Records like this are being made in scores of brass and bronze foundries using Detroit Electric Furnaces. They can be duplicated in your own foundry with this fast melting, flexible furnace. Write for complete information.

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A Spectroscope for Converter Blow*

TO PRODUCE a steel to strict chemical and mechanical specifications, the end of the blow in a converter must be accurately determined. Underblowing gives a steel with a high percentage of impurities. An overblown heat will cause difficulties in casting, show a low carbon content, high metal losses and excessive lining wear.

Although photo-electric cells are used in a few large plants to indicate this important end of the blow the unaided human eye is still more widely used but even an experienced man is not infallible. A miniature direct vision spectroscopic slit in the outer tube and a compound direct vision prism in a sliding tube. The development of the converter flame during the blow and the appearance and disappearance of certain spectrum lines can be observed with this spectroscope.

A very faint continuous spectrum appeared at the beginning of the blow and grew stronger as the flame became brighter. The most pronounced yellow band appeared when boiling began. The time between the start of the blow and the appearance of the yellow band varied with the temperature of the metal and the converter lining. When ejection ceased, a green band, faint at first, appeared. During the carbon flame two other green bands and two red bands became visible. The time between the appearance of the yellow band and the green and red bands varied due to the irregular composition of the cupola metal and the addition of ferro-silicon during the blow. At times a blue band was discernible. The complete disappearance of the yellow, green and red bands indicated that the blow was finished and the carbon near 0.1%.

While the wave lengths of the bands were not measured, there was a very definite relationship between the bands in the flame spectrum and the composition of the metal. This leads directly to the application of the "electric eye" to the Tropenas converter to attempt a more rigid control of the process.

*Abstracted from "The Control of Tropenas-Converter Blowing by a Direct-Vision Spectroscope", by S. T. Jazwinski, Iron and Steel Institute Advance Copy, June 1945.

By L. E. Ekholm
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Alan Wood Steel Co.
Conshohocken, Pa.

"H" Steels and Their Specification

Alloy steel producers have for some time realized the commercial importance of steels having controlled hardenability characteristics, both in manufacture and use. It was appreciated, however, that this type of steel would require a radical departure from the present method of specifying steel to chemical limits only.

Recognizing the importance of this problem, the Technical Committee on Alloy Steel of the American Iron and Steel Institute started a research program to determine if it were possible to develop hardenability specifications which could be used for the manufacture and for the use of alloy steels. This committee worked closely with the Iron and Steel Committee of the War Engineering Board and the Iron and Steel

Division, General Standards Committee, of the Society of Automotive Engineers, Inc.

Any standard hardenability specification would of necessity be subject to the following broad conditions:

1. It would be necessary to have a rapid and accurate method of determining hardenability which could be written into a specification and which could be used for acceptance and rejection.

2. The making of steel to hardenability limits would have to be practical in relation to present day methods for the production of alloy steel. Any hardenability specification would have to include present chemical limits as a minimum and could not increase the number of "off" heats.

3. Any specification developed would have to be practical from the consumer's viewpoint, that is, the specification must permit the purchaser to obtain steel with hardenability limits sufficiently narrow to allow him to control the heat treating operations more uniformly.

The Alloy Technical Committee used as a basis of its work the end-quench method of determining hardenability. This method and its characteristic curves have become a standard, by popular acceptance and use. Detailed study of this method by the committee has led to the following conclusions:

1. Reasonably close checks can be obtained on different tests from the same heat of steel in the same laboratory and in different laboratories.

"H" Steels; Chemical Composition Ranges

(Electric Furnace or Openhearth Bars, Billets or Blooms)

S.A.E. or A.I.S.I. Designation	Chemical Composition*					
	C	Mn	Si	Ni	Cr	Mo
2512 H	0.08/0.15	0.35/0.65	0.20/0.35	4.70/5.30	—	—
2515 H	0.11/0.18	0.35/0.65	0.20/0.35	4.70/5.30	—	—
2517 H	0.16/0.21	0.35/0.65	0.20/0.35	4.70/5.30	—	—
3310 H	0.07/0.14	0.35/0.65	0.20/0.35	3.20/3.80	1.35/1.75	—
3316 H	0.13/0.20	0.35/0.65	0.20/0.35	3.20/3.80	1.35/1.75	—
4130 H	0.27/0.34	0.35/0.65	0.20/0.35	—	0.80/1.15	0.15/0.25
4132 H	0.30/0.37	0.35/0.65	0.20/0.35	—	0.80/1.15	0.15/0.25
4135 H	0.32/0.39	0.60/0.95	0.20/0.35	—	0.80/1.15	0.15/0.25
4137 H	0.35/0.43	0.60/0.95	0.20/0.35	—	0.80/1.15	0.15/0.25
4140 H	0.37/0.45	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4142 H	0.40/0.48	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4145 H	0.42/0.50	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4147 H	0.44/0.52	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4150 H	0.46/0.54	0.70/1.05	0.20/0.35	—	0.80/1.15	0.15/0.25
4317 H	0.14/0.21	0.40/0.70	0.20/0.35	1.50/2.00	0.35/0.65	0.20/0.30
4320 H	0.16/0.23	0.40/0.70	0.20/0.35	1.50/2.00	0.35/0.65	0.20/0.30
4340 H	0.37/0.45	0.60/0.95	0.20/0.35	1.50/2.00	0.65/0.95	0.20/0.30
4620 H	0.17/0.24	0.40/0.70	0.20/0.35	1.50/2.00	—	0.20/0.30
4640 H	0.37/0.45	0.55/0.85	0.20/0.35	1.50/2.00	—	0.20/0.30
4815 H	0.12/0.19	0.35/0.65	0.20/0.35	3.20/3.80	—	0.20/0.30
4820 H	0.17/0.24	0.45/0.75	0.20/0.35	3.20/3.80	—	0.20/0.30
8620 H	0.17/0.24	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8622 H	0.20/0.27	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8625 H	0.22/0.29	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8627 H	0.25/0.32	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8630 H	0.27/0.34	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8632 H	0.30/0.37	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8635 H	0.32/0.39	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8637 H	0.35/0.43	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8640 H	0.37/0.45	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8642 H	0.40/0.48	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8645 H	0.42/0.50	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8647 H	0.44/0.52	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8650 H	0.46/0.54	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8720 H	0.17/0.24	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8722 H	0.20/0.27	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8725 H	0.22/0.29	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8727 H	0.25/0.32	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8730 H	0.27/0.34	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8732 H	0.30/0.37	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8735 H	0.32/0.39	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8737 H	0.35/0.43	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8740 H	0.37/0.45	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8742 H	0.40/0.48	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8745 H	0.42/0.50	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8747 H	0.44/0.52	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8750 H	0.46/0.54	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
NE 9420 H	0.17/0.24	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9422 H	0.20/0.27	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9425 H	0.22/0.29	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9427 H	0.25/0.32	0.80/1.15	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9430 H	0.27/0.34	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9432 H	0.30/0.37	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9435 H	0.32/0.39	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9437 H	0.35/0.43	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9440 H	0.37/0.45	0.85/1.25	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9442 H	0.40/0.48	0.95/1.35	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9445 H	0.42/0.50	0.95/1.35	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9447 H	0.44/0.52	1.15/1.55	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
NE 9450 H	0.46/0.54	1.15/1.55	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15

NOTE — NE denotes National Emergency Standard Steel.

General Notes

These chemical compositions apply to steels produced to definite hardenability limits as shown in the tentative bands sketched on pages 676 to 683. These bands are determined by the standard end-quench on 1-in. round bars, commonly called the "Jominy test" and as outlined in S.A.E. Standard End-Quench Hardenability Test modified June 1944. Composition limits and hardenability bands are intended to apply to steels manufactured to "fine-grained steel practice".

Sizes and Shapes — The ranges and limits in this table apply only to material not exceeding 100 sq. in. in cross-sectional area, or 18 in. in width, or 7000 lb. in weight, per piece as the total product of the ingot, and exclude all plate, shapes, sheet, strip and slabs.

*Permissible Chemical Variations

Phosphorus and sulphur in openhearth steel to be 0.040% max. each.

Phosphorus and sulphur in electric furnace steel to be 0.025% max. each.

Small quantities of certain elements may be found in alloy steels which are not specified or required. These elements are to be considered as incidental and acceptable to the following maximum amounts: Copper 0.35%, nickel 0.25%, chromium 0.20%, molybdenum 0.06%.

The chemical ranges and limits shown are subject to the standard permissible variations for chemical analysis over the maximum limit or under the minimum limit. These permissible variations are: 0.01 for all ranges of carbon; 0.03 for manganese up to and including 0.90% and 0.04 for over 0.90 to 1.55% inclusive; 0.005 for either phosphorus or sulphur; 0.02 for silicon; 0.03 for nickel up to and including 1.00%, 0.05 for nickel over 1.00 up to and including 2.00%, and 0.01 over 2.00 up to and including 5.30%; 0.03 for chromium up to 0.90% inclusive, and 0.05 for chromium over 0.90 to 1.75% inclusive; 0.01 for molybdenum up to 0.20% inclusive, 0.02 for molybdenum over 0.20 to 0.30% inclusive.

Quality Conditions — All conditions and quality features, except as detailed above, shall be in accordance with the regulations shown in the American Iron and Steel Institute's "Steel Products Manual", Section 10 on Alloy Steels.

2. Reasonably close checks can be obtained from different positions in the same heat and from different locations in the same ingot.

3. A quick test for the hardenability characteristics to be expected from a heat of steel when it is ready for delivery can be made by pouring a test specimen on the openhearth platform. Reasonably close checks can be obtained between this "cast test", and forged or rolled tests taken from other parts of the heat.

After the method of determining hardenability had been adopted, the Alloy Technical Committee made a statistical study of all available data to determine the relative hardenability limits of numerous types of steels and the relative positions of each steel within a given series. In this statistical work the Committee studied thousands of heats of alloy steel, and it was found by the use of frequency curves that the great majority of heats of like chemistry fell within a comparatively narrow band of hardenability (end-quench test). This was true even though these heats had been melted to full standard chemistry limits.

Two other interesting facts came to light during this study:

1. A number of heats which had been "missed" in chemistry, that is, were outside of the standard chemistry range in one or more elements, fell within this narrow band. This point is very important and indicates that from a practical viewpoint these heats should never have been considered rejectable.

2. Some heats which were chemically satisfactory were outside of this comparatively narrow hardenability band.

The above two facts are not surprising when one understands the balancing of different elements in a steel's composition. There are times when the elements having the greatest effect on hardenability are all on the low side (or on the high side) of the standard chemistry range. This condition is responsible for steels of very low (or very high) hardenability. In most of the steels, however, an element on the low side was compensated for by one or more elements on the high side, or vice versa, with the result that these

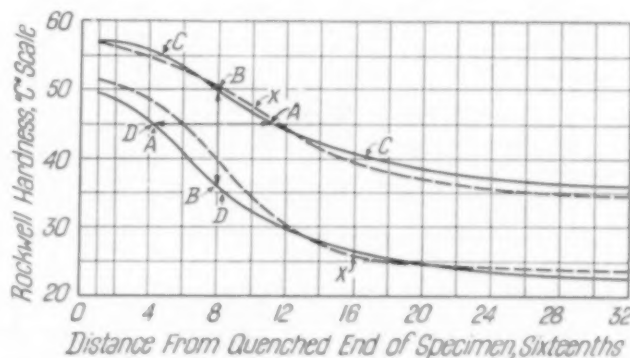


heats fell within the comparatively narrow hardenability band.

The data used in this rather extensive study showed that each steelmaking plant has definite individual melting techniques and characteristics which influence the hardenability of the product. In order to allow the steel producers, during their normal manufacturing operations, to make proper adjustments in the steel's chemistry to correct for these individual characteristics, the present standard chemical compositions would have to be widened slightly. This would be necessary in order

to permit all steel producers to melt to a narrow hardenability band without requesting individual modifications of chemistry.

After completion of this research program and statistical study, the results of the work of the Alloy Technical Committee were compared with the data accumulated by the S.A.E. committee. The comparison was favorable, and a definite policy was established as to the method for developing a number of hardenability bands which would be tentatively satisfactory to the steel producers and steel consumers. A group of bands were established in this way which were a great deal narrower than would have been practical if they had been established solely on stand-



The Various Methods of Specifying Hardenability Requirements of the "H" Steels: Any two points on either the maximum or the minimum hardenability curve (or any one point on both of the full lines), plus the maximum and minimum hardenability at 1/16 in., may be specified. If more than these points are specified a variation of two points on the hardness scale is permissible, as shown in the dotted lines

ard chemistry limits. The bands and the respective chemical limits of these so-called "H" steels are shown in the adjoining pages, copied from the most recent publication of the American Iron and Steel Institute on "Hot-Rolled Alloy Steels".

These bands are still "tentative" rather than "standard", inasmuch as they were established from data obtained on steel which had been melted solely to chemistry limits. Data are now being accumulated on heats definitely made as "H" steels—that is, melted to hardenability limits, and when sufficient experience is gained on the manufacture and use of these tentative specifications, they will be reviewed. These bands will then be established either as standard or modified as experience dictates.

Those who are interested in the details of the work of the Technical Committee on Alloy Steel of the American Iron and Steel Institute described briefly above are referred to the 1944 Yearbook of the American Iron and Steel Institute. The articles referred to are "Some Aspects of Commercial Production of Alloy Steels to Hardenability Requirements" by W. G. Bischoff, and "Principles Involved in Determining Hardenability Limits of Alloy Steels" by L. L. Ferrall.

An account of the end-quench hardenability test is unnecessary inasmuch as it has been fully discussed in *Metal Progress* and *Transactions*. The Society of Automotive Engineers, Inc. has published this method of determining hardenability as an S.A.E. recommended practice in its

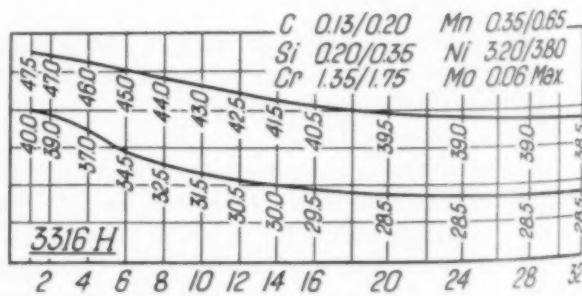
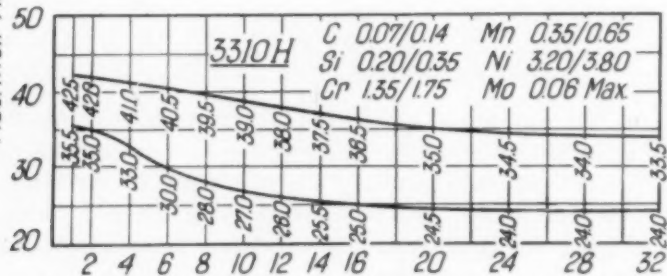
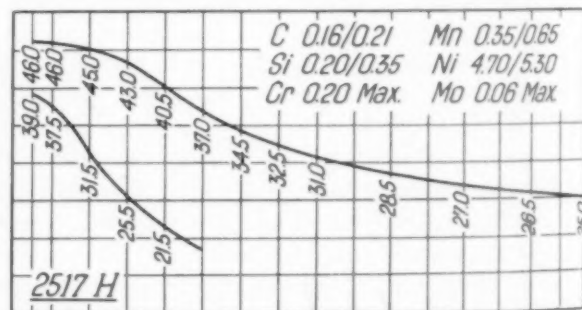
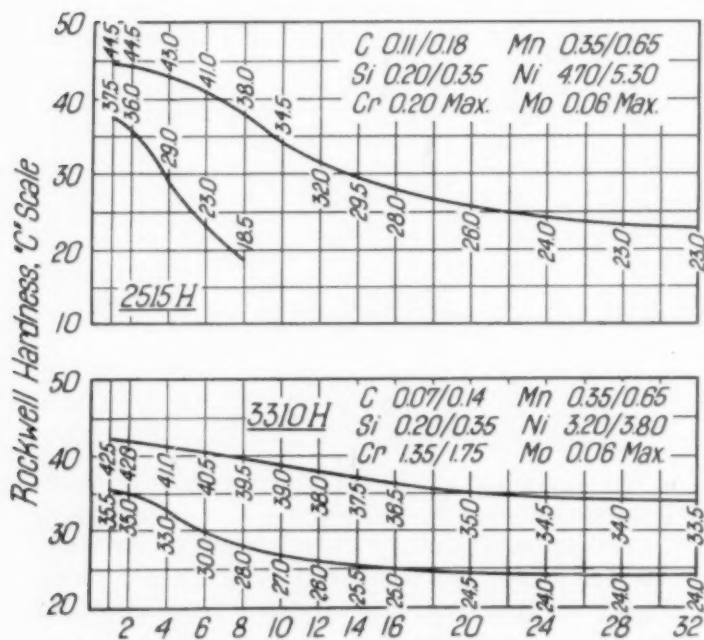
latest Handbook. Published with this method is a detailed bibliography covering the literature on this subject.

Methods for Specification and Purchase

When specifying "H" steels it should be realized that two things are being specified, a *property* of the steel as well as a particular *type* of alloy steel. When a given type of steel is chosen, the important part of specifying the correct steel is for the purchaser to know the limits of hardness required for a given section. Methods for determining what hardenability limits should be specified have been fully discussed by Walter E. Jominy, whose name the end-quench test bears, in *Metal Progress* for November 1940, page 685; January 1943, page 77; June 1944, page 1096.

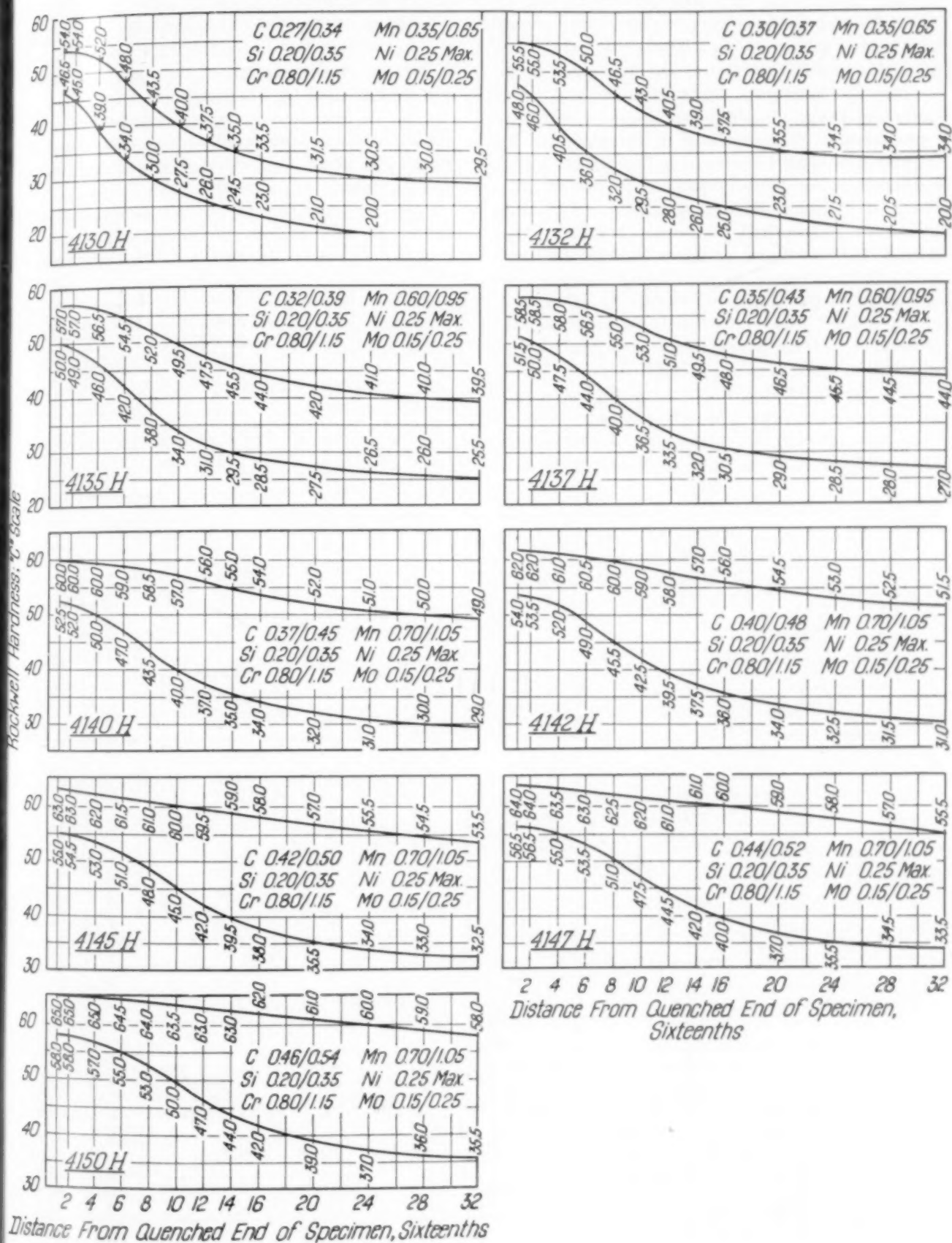
When the proper hardenability requirements for a given part have been satisfactorily determined by the purchaser, the specifications are

(Continued on page 678)



Distance From Quenched End of Specimen, Sixteenths
Hardenability Bands for Steels 2512 H to 3316 H, Inclusive

Hardenability Bands for Steels 4130 H to 4150 H, Inclusive



ready to be given to the alloy steel producer. Besides specifying the type of steel such as "8735-H" the hardenability requirements should be specified as two points. These two points may be designated in any one of the following ways:

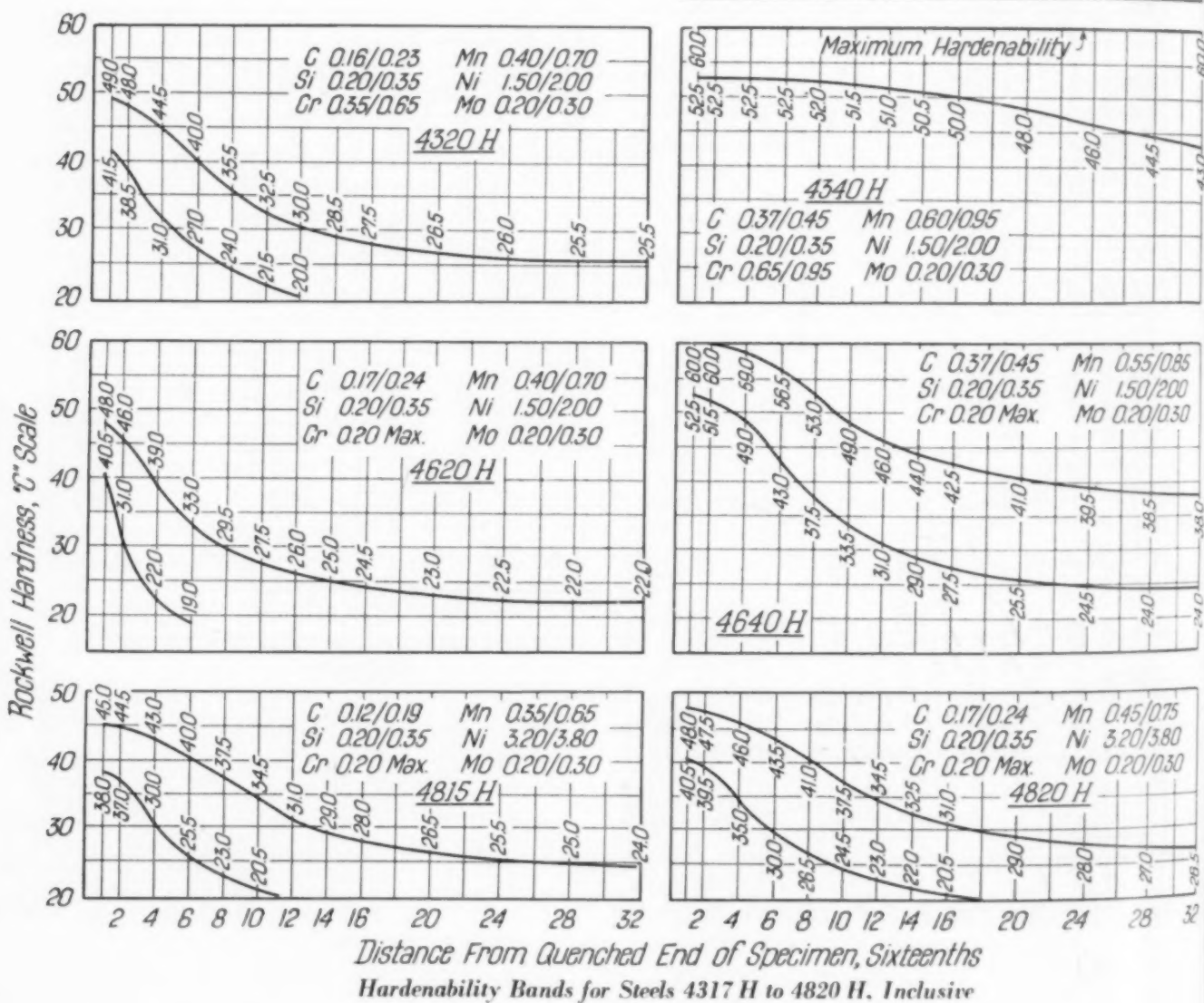
A. By specifying the minimum and maximum distances at which any desired hardness value occurs. This method is illustrated in the figure on page 675 (taken from the A.I.S.I. publication on "Hot-Rolled Alloy Steels") as Points A-A and could be specified as " J_{45} equals 4 and 11 sixteenths". (In this notation, " J_{45} " means "C-45 hardness as determined by the Rockwell hardness tester on a standard Jominy bar quenched in the standard manner" and "4 and 11 sixteenths" represents the distances from the quenched end of the Jominy test bar within which that hardness must fall.)

B. By specifying the minimum and maximum hardness values at any desired distance from the quenched end of the Jominy bar. This method is illustrated as Points B-B and

could be specified for those curves as " J_{38} to J_{46} equals 6 sixteenths". Obviously the distance selected would be that distance on the end-quench test bar which has a cooling rate corresponding to the important portion of the part to be made and heat treated by the consumer.

C. By specifying two maximum hardness values at two desired distances, illustrated as Points C-C, thus: " J_{55} equals 5 sixteenths (max.) and J_{40} equals 17 sixteenths (max.)".

D. By specifying two minimum hardness values at two desired distances, illustrated as Points D-D, thus: " J_{45} equals 4 sixteenths (min.)



and J_{as} equals 8 sixteenths (min.)".

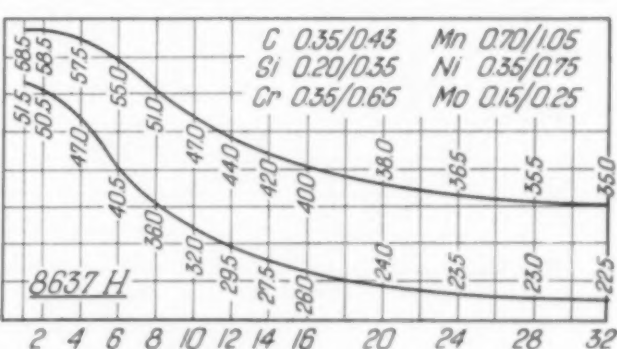
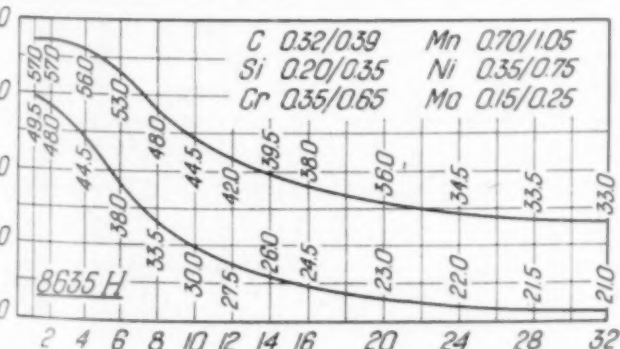
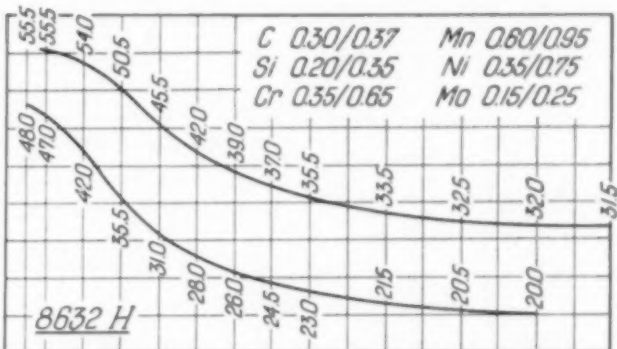
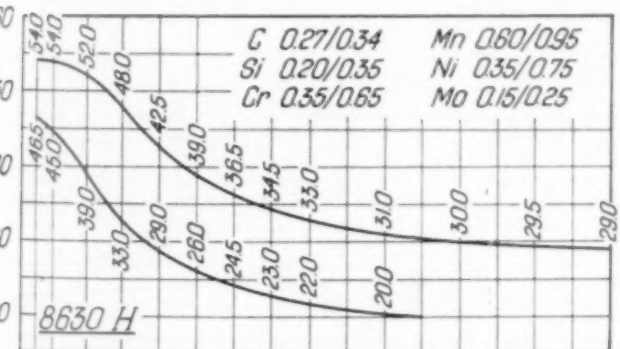
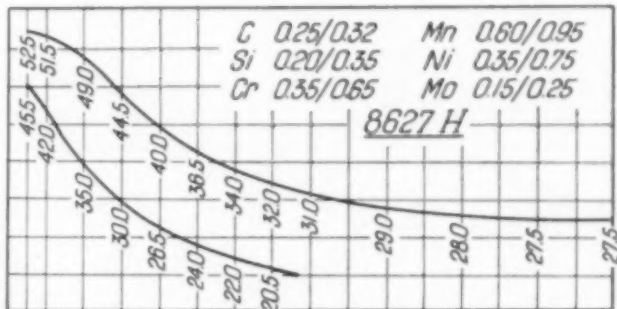
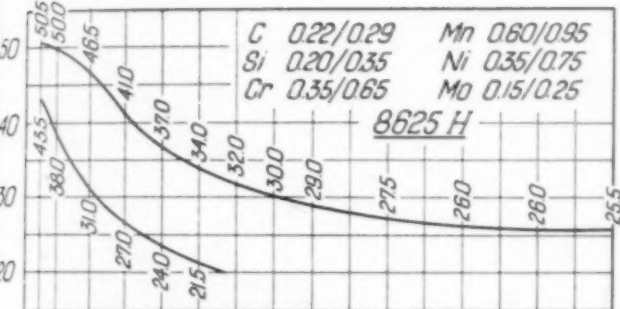
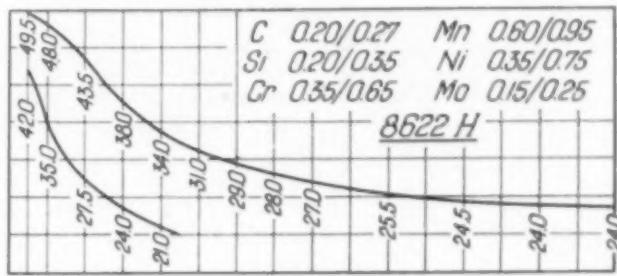
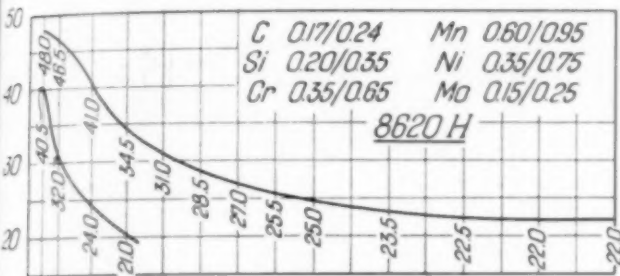
E. By specifying any point on the minimum hardenability curve plus any point on the maximum curve.

In purchases where it is considered desirable, the maximum and minimum limits at the $\frac{1}{16}$ -in. point may be included in addition to the other two points. Such instances would be for parts that require close limits of surface hardness.

For such parts where it is necessary to specify more than the $\frac{1}{16}$ -in. point and two others

located somewhere on the full length of the upper or lower limiting curve or both, it is necessary to permit a tolerance of two points on the Rockwell C-scale along a small portion of either curve. This is necessary because it will be found that curves for individual heats may vary somewhat in shape from the standard band limits as shown; the results of the test may at some locations exceed slightly the maximum or minimum curve specified. Such deviations, up to not more than

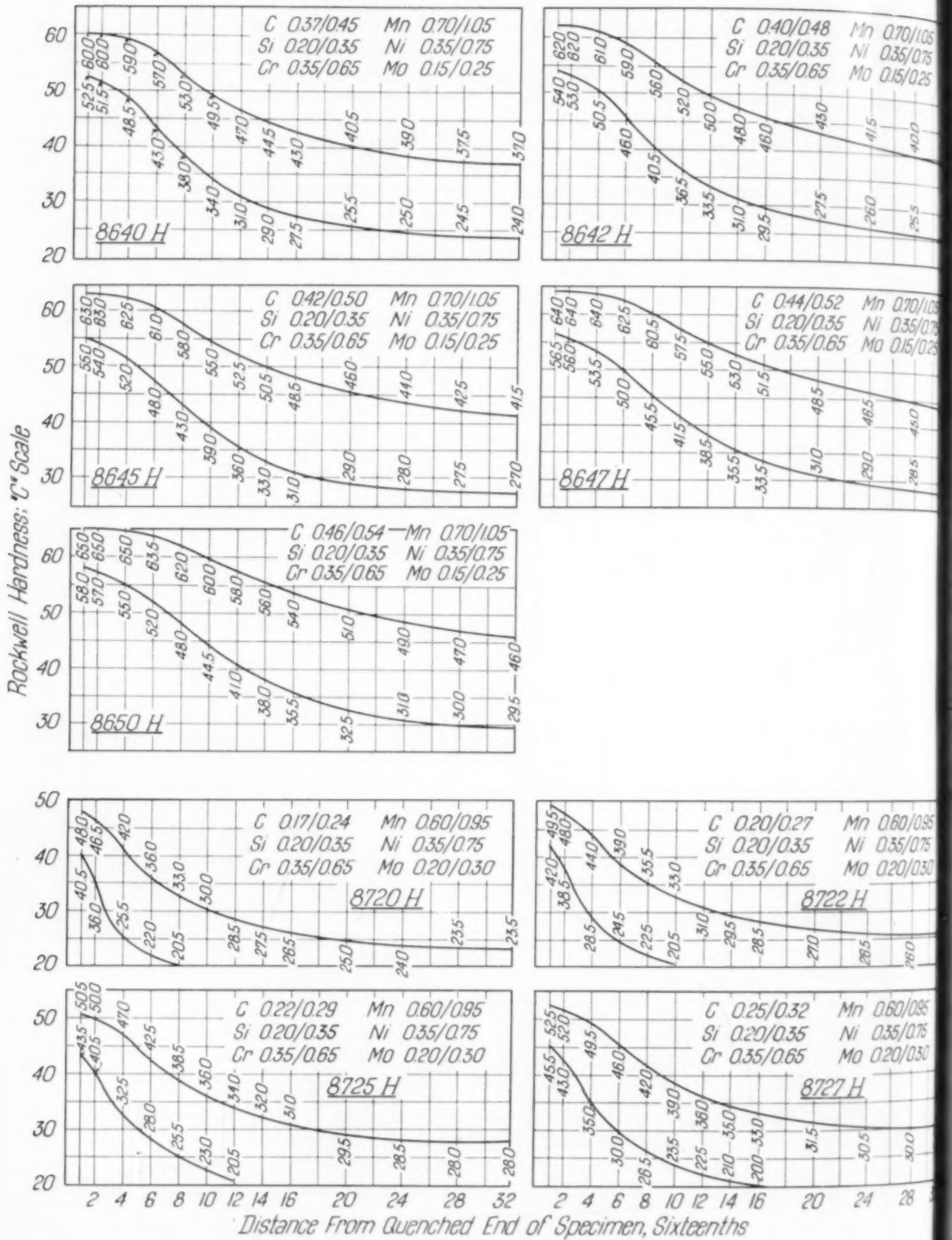
(Continued on page 682)



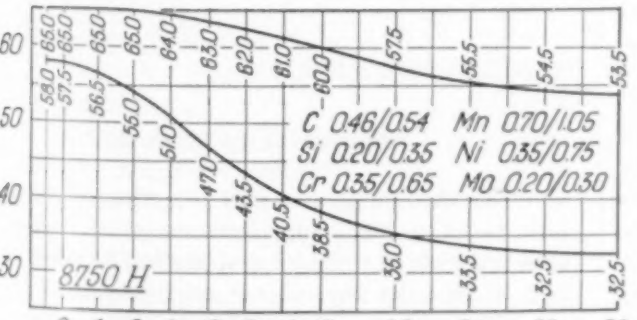
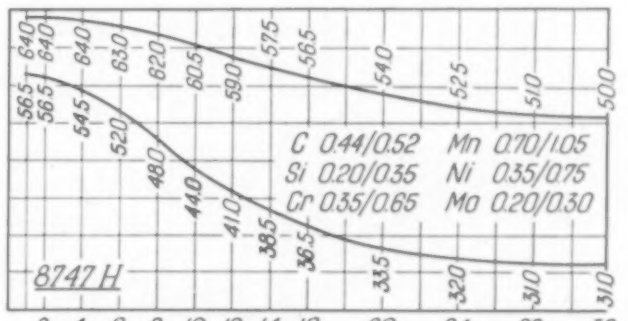
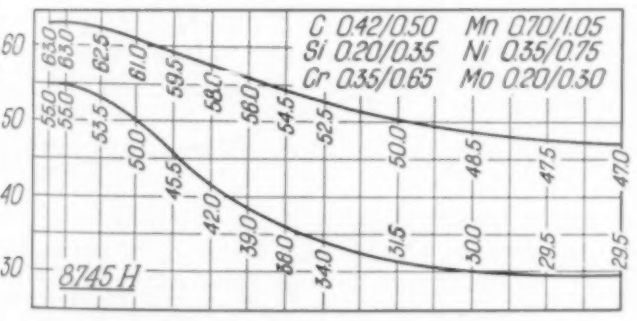
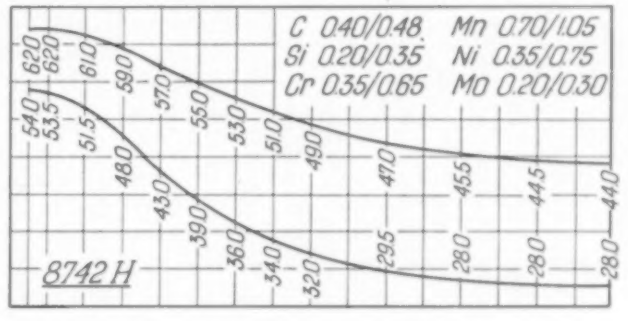
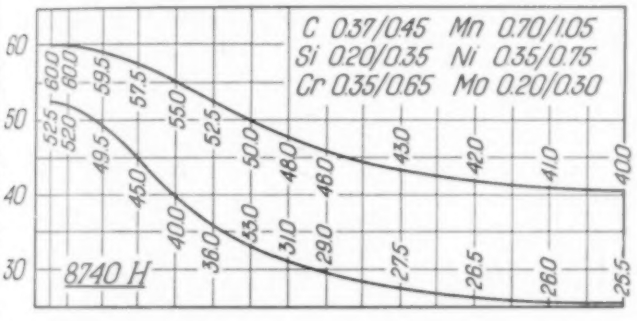
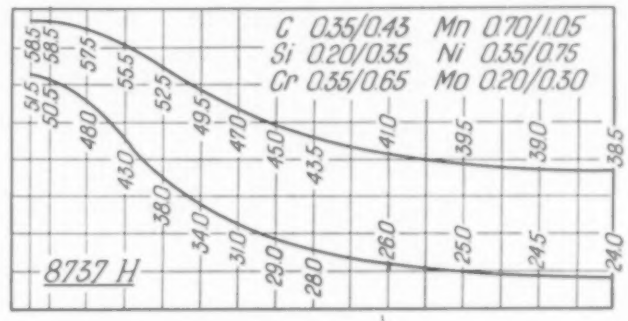
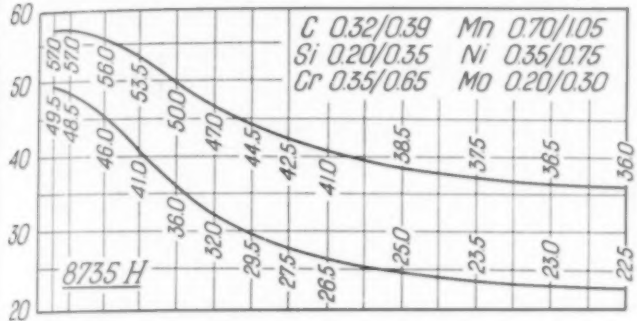
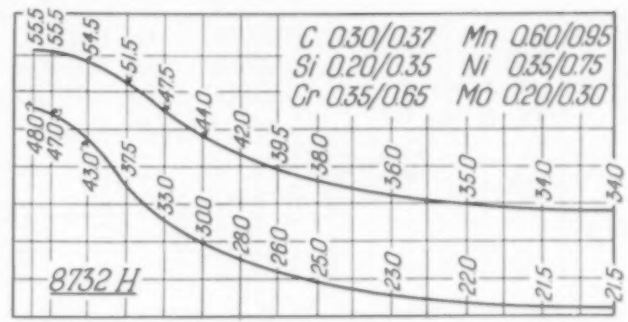
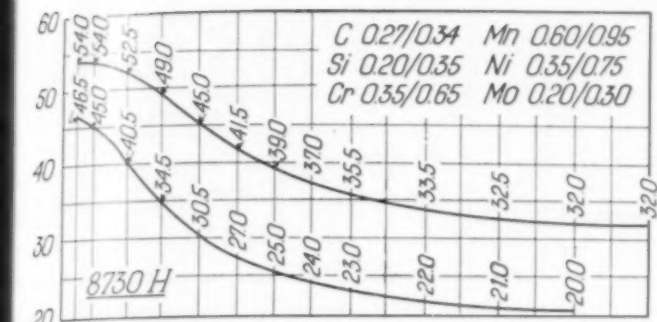
Distance From Quenched End of Specimen, Sixteenths

Hardenability Bands for Steels 8620 H to 8637 H, Inclusive

Hardenability Bands for Steels 8640 H to 8727 H, Inclusive



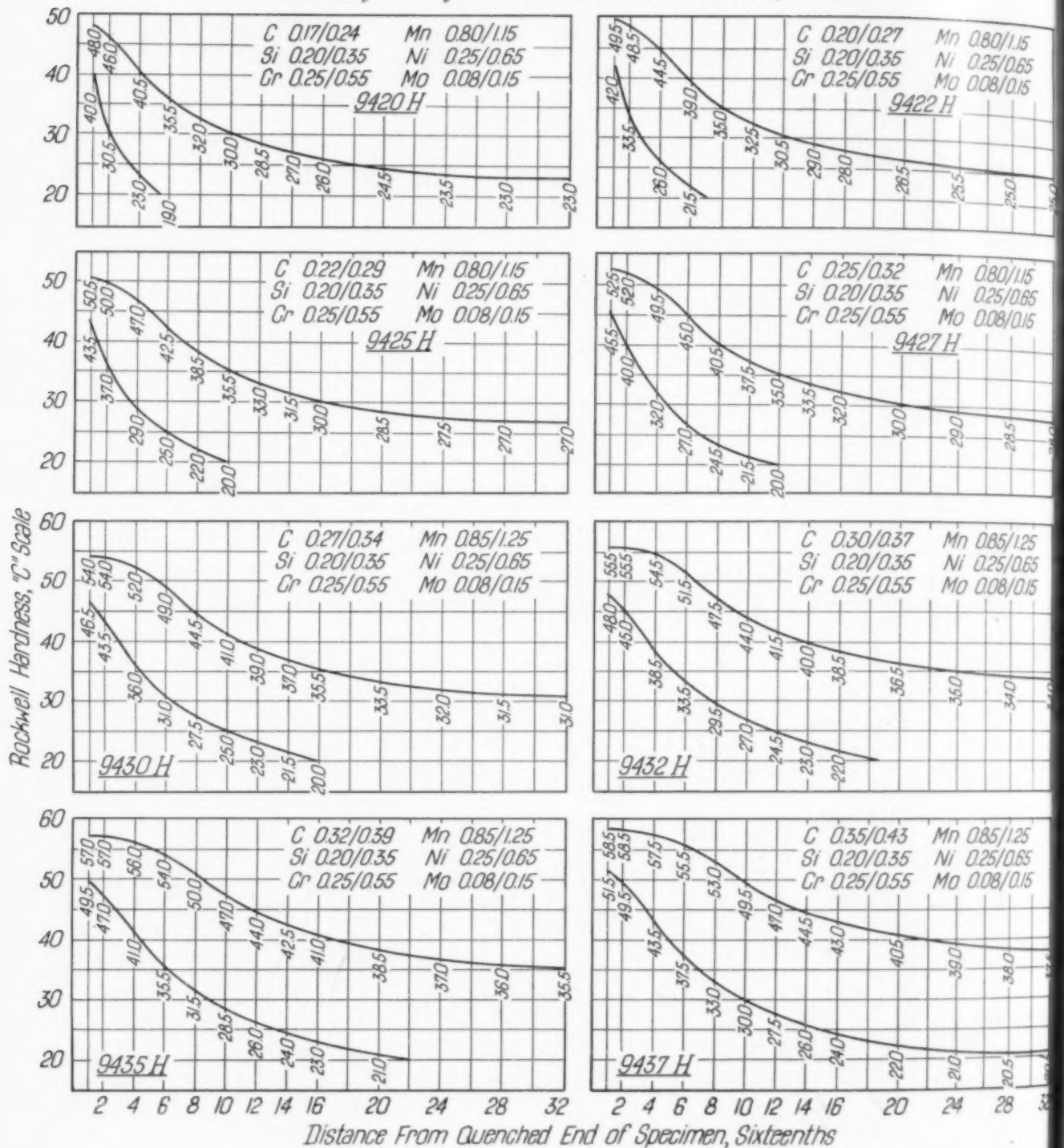
Hardenability Bands for Steels 8730 H to 8750 H, Inclusive



Distance From Quenched End of Specimen,
Sixteenths

Distance From Quenched End of Specimen, Sixteenths

Hardenability Bands for Steels NE 9420 H to NE 9437 H, Inclusive



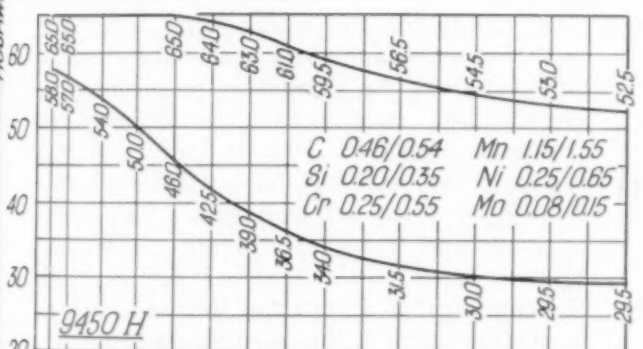
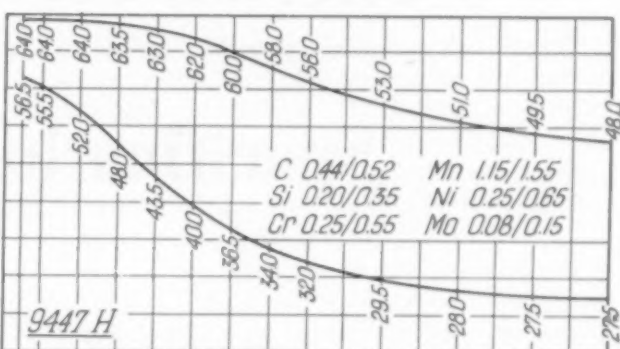
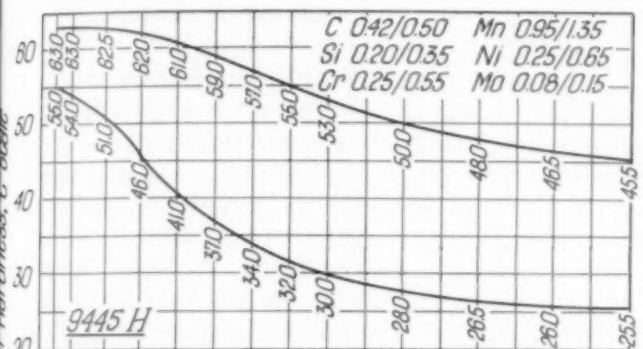
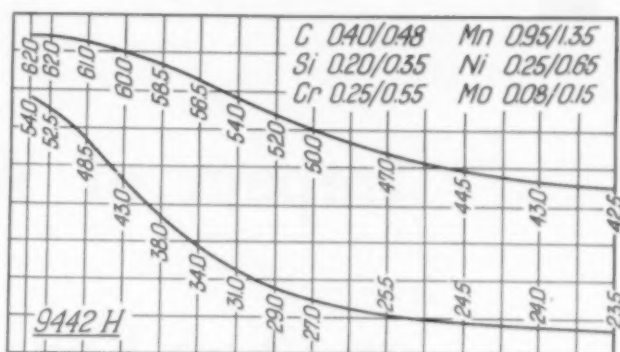
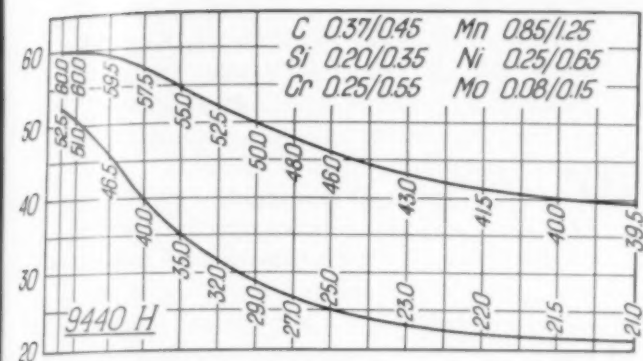
two points Rockwell C, are illustrated by the dotted curves marked X in the figure and are to be considered permissible when more than two points (either with or without the limits at the $\frac{1}{16}$ -in. point) are specified.

When two points only are specified (either with or without the limits at the $\frac{1}{16}$ -in. point), the individual "H" steel shall meet the requirements set forth as shown in its hardenability band and the hardness values in the diagrams.

Standard Test Methods

For the acceptance and rejection of material purchased to "H" specifications it is necessary that a standard technique of testing be used. The test to be used for referee purposes must be in accordance with all of the details outlined in S.A.E. Recommended Practice for Determining Hardenability, as published in the 1945 S.A.E. Handbook.

Hardenability Bands for Steels NE 9440 H to NE 9450 H, Inclusive



Distance From Quenched End of Specimen, Sixteenths

There are a number of details in the testing for hardenability which are very important in that they have marked effects on the results:

1. Temperature prior to quenching.
2. Protection of the test pieces from scaling and decarburization.
3. Carefully calibrated Rockwell hardness testing machines.
4. Proper holding or seating of test specimen during hardness testing.
5. Grinding of flat on specimen without heating it enough to temper it.

With full attention to all details of testing very little discrepancy between the laboratory results of steelmaker and consumer would be expected.

It is believed that the specification and manufacture of alloy steels to the "H" system is a

long step forward in metallurgical control from raw material to finished product. Under this system a consumer can specify a given type of steel with full assurance that the steel will, after proper fabrication, properly respond to heat treatment. The selection and specifying of steels can now be done more scientifically than has been possible up to this time. The steel consumer now knows, when using this type of specification, what hardness values he will obtain, minimum and maximum, in a heat treated section after he has correlated his heat treating procedures with the end-quench test.

Using the hardenability method of specifying alloy steels, the consumer metallurgist will be able to:

1. Heat treat with minimum distortion.
2. Readily select a steel for a given part without emphasis on the "alloy rich" side of the analysis, as has been customary to compensate for a few heats low in hardenability.
3. Set heat treating procedures with assurance that the products of heat treatment will be within the stipulated requirements.
4. Avoid radical changes in heat treatment from one heat to another, because heats of exceptionally high and low hardenability ranges are eliminated.

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Staff Engineer
American Society for
Testing Materials
Philadelphia

Impact of War on Non-Ferrous Specifications

WHAT AFTER-EFFECT will our wartime specifications, substitutions and down-grading have? Have the changes come to stay? Or will we go back to our oldtime status just as soon as possible? Those are some of the questions that many have been asking. Perhaps the best way to forecast the future is to review some of the past to see what clues to the answers may be furnished thereby.

Experience of the past few years of war economy has taught us many things about material specifications and the specifying of materials. Those two—specification and specifying—are not the same, although closely related and complementary. Proper recognition of this fact and of their relative fields is important. An understanding of this shows why much more can be accomplished by intelligent cooperative action than by legislation or direction.

Wartime demands for metals exceeded our supply—that was soon evident. Something had to be done. Critical and strategic metals had to be restricted to *essential* use. As months went on there was no change in that fundamental policy, but dictated by the available supply there were, of necessity, changes in what could be considered essential. Metal had to be used in the right place at the right time. That was the real problem—the efficient and effective use of material. It was no one-man job; no one-organization job, either. It was teamwork—by the Army, the Navy, the Maritime Commission and other

government departments and agencies, and by industry. Better utilization of materials was the common aim of all.

We mentioned above “material specifications and the specifying of materials”. Just how do they fit into this picture? Material specifications are the province primarily of the materials engineers—the specification writers. A specification defines a material within certain limits; that “within” is important. A metal specification, for instance, may give a minimum tensile strength and a minimum elongation. That

gives the upper and lower limit, for when the metal far exceeds the tensile strength it will probably not meet the elongation requirement. The specification, once written, is the tool of the designing engineer. It tells him what he may expect of the material and consequently whether it will meet his requirements. The materials engineer may write, or change, specifications to his heart's content but unless that specification is a useful *tool* it will not be used, and is not worth the paper it was written on.

Specifications, therefore, are—or certainly should be—carefully written. There should be a balance between what the consumer wants and what the producer can give at the price the consumer will pay. (If you want specialties and are willing to pay for them, you can usually get them.) To write a good, well-balanced specification usually takes time. When there was no reason for restrictions on the use of material it was our custom to write rather exacting ones—more exacting than we actually needed when we faced the facts squarely, or else the story of the past few years would not have been written as it was.

The emergency of war forced, first of all, speed of action. The materials engineer met that with the “Emergency Alternate” specifications. The method of promulgating them was

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different from that of the normal leisurely specification writing. Short cuts were taken so that they could be published and available promptly. But, because of that they could not be made mandatory. If the design engineer had specified a certain material assuming certain properties, he could not be forced to take a modification as a substitute. If, as was the case, he continued to be responsible for performance, any substitute had to be his free choice with all the available facts before him.

Now the design engineer was used to careful action too, and, much to the disappointment of the materials engineer, he would not always accept what was offered. Nor can he be blamed too much for that. Yet the emergency alternate specifications performed a useful function. They focused attention on desirable changes such as thinner protective coatings for items whose life was known to be limited, wider limits of chemical composition, especially impurity limits, in standard alloys, and so on. They paved the way for future action but did not in all instances attain immediate or complete acceptance, for as Lewis Carroll might have said it:

It had softly and silently vanished away
For the Spec. was an Option, you see.

What action could be taken and what action was taken? As a matter of fact there were two. First and most important: A critical examination of end use. Emphasis was laid on changes in specification use rather than changes in specifications themselves. The objective is still efficient use of material. If secondary material is available where primary isn't, then specifications for alloys that can be made from that secondary material should be used if they can be. If a bronze with lower tin than one that had been used is equally serviceable, or safely so, it should be used to conserve tin. But to say *whether* it could be used was the design engineer's responsibility.

Recognition of proper fields of action and responsibility along with mutual respect and cooperation between the materials engineers and the design engineers was the basis of conservation of many of our critical and strategic materials as will be outlined below. Failure to recognize these factors led to the promulgation of other specifications whose utility and life were limited. It also led to a number of attempts to force specification use by fiat, with some definitely undesirable results.

It has been pointed out that the emergency alternate specifications served a useful purpose but were not mandatory. As we settled down to the long pull to victory, stock was taken of the

situation and changes made. Many of the emergency alternate provisions, or modifications thereof, were incorporated in standard specifications, some as war amendments subject to review six months after the war is over.

So much for the general picture. Let us now examine in some detail each of the principal non-ferrous metals to see how they were affected by various moves in specifications, substitutions and down-grading. At the same time we will try to estimate what the after-effect will be.

Aluminum and Magnesium

Aluminum and magnesium are not intended to be covered specifically in this story and hence are mentioned only briefly. Before the war only a relatively small amount of magnesium was available. The tremendous increase in production is something of which we can well be proud as a real American achievement.

To only a slightly less degree the same can be said of aluminum. But here was a metal of wide peacetime usage where normal channels were disrupted for a while. The angle that affects us chiefly in this review is the repercussions of the early aluminum shortage on zinc die castings as discussed later.

Magnesium at first was exceedingly short, even too short to be used as an alloying element with aluminum. Some Federal emergency alternate specifications were written to cover these by substituting other alloys. But as most of these aluminum alloys were being used in aircraft it seems doubtful if these specifications were used to any great extent and they were among the earliest to be canceled. So too were alternate specifications for other aluminum alloys which merely substituted other metals, at the time relatively more available.

Copper

Copper, as well as aluminum, was cut off from its many peacetime uses early in the war. As time passed until we reached peak wartime production in 1944 the restrictions on copper use were drawn tighter and tighter.

The first impact of these restrictions upset many normal channels of trade. While we needed still more and more primary copper for ammunition and other wartime uses, the supply of copper scrap was mounting. Much of this then was radiator scrap from junked automobiles, automobiles which were salvaged primarily for steel scrap. Another factor contributing to the accumulation of low grade copper scrap in 1942

was the fact that peacetime products normally made of such material were among the first group of items restricted by War Production Board's Copper Conservation Order M-9-c.

So far as uses of wrought copper alloys were concerned, those not directly connected with war matériel and the maintenance of health and safety were prohibited by Order M-9-c. Restrictions on manufacture of other civilian items such as automobiles and refrigerators also released primary copper earmarked for their use. Where "essential" articles, such as clocks, continued to be made with substitutes, the results were far from satisfactory. There were too many such substitutions to enumerate them all, but I believe that we can assume that most of these fields of use will be regained by copper and its alloys — just as they were after the last war.

Committee B-5 on Copper and Copper Alloys were foresighted enough to give the specification for cartridge brass known as B19 a thorough overhauling, representatives of Army Ordnance from Washington and Frankford Arsenal cooperating.

The object was to have B19 and the corresponding specifications enforced by the armed services in such form that the arsenals could get the material they needed and the brass mills could get into volume production. The specifications for gilding metals were also reviewed. That work was finished long before Pearl Harbor, and Ordnance and the mills had specifications that were satisfactory — and as for volume production, never in the history of the world has there been anything to match it!

The development of steel cartridge cases as a substitute for brass is another story and has

Table I—Changes in Specifications for Free Cutting Brass Rod

ELEMENT	B16-18	B16-29 B16-41 QQ-B-611a APR. 27, '38	E-QQ-B- 611a AUG. 14, '42	PROPOSAL No. 2 (SEE TEXT)	B16-42 B16-44 QQ-B-611a AUG. 24, '42 AMENDMENT No. 2	EA B16 QQ-B-611a MAY 27, '44 COMPOSITION B AMENDMENT No. 4
Copper	60.0 to 63.0	60.0 to 63.0	60.0 to 63.0	60.0 to 63.0	60.0 to 63.0	60.0 to 63.0
Lead	2.25 to 3.25	2.50 to 3.75	2.50 to 3.75	2.50 to 3.75	2.50 to 3.75	2.50 to 3.75
Tin (max.)	...	...	0.30	0.50	...	0.30
Iron (max.)	0.15	0.15	0.50	0.50	0.15	0.35
Nickel (max.)	...	...	1.00	1.00	...	0.50
Total others (max.)	...	...	0.50	0.50	...	0.50
Other than Cu+Pb+Fe+Zn	...	...	...	...	0.50	...
Other than Cu+Pb+Zn	0.25	0.50	...	...	...	...
Zinc	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

The principal change in specifications in the wrought alloy field was, in all alloys where electrical conductivity was not a primary factor — including cartridge brass — to permit the use of high grade fire-refined copper principally from South America and Arizona. Another important change was in removing the restrictions on the use of scrap of known purity. No longer did Federal specifications say: "Only primary metal shall be used"; they said instead: "The metal used shall be such as to meet the chemical requirements of this specification." That change was not limited to wrought copper either. It was quite general for all metals and other specifications have generally followed the same principle. These changes proved desirable and it seems safe to say they will continue.

Cartridge Brass—The story on cartridge brass specifications goes back some years before the war — to 1938 in fact. About that time the officers of American Society for Testing Materials'

been covered in detail in past issues of *Metal Progress*. It was a really great metallurgical achievement and at its peak was saving some 25,000 tons of copper per month. When the copper supply eased, though, the program was generally dropped except to retain pilot lines should the need arise again. Should acute need arise in the future we have the knowledge and skill to take it up again.

There was one slight disturbance in the cartridge brass specification situation in the summer of 1942. The copper limits (which had been 68 to 71% for the Army in the last war and 68 to 70% for the Navy) were 68.5 to 71.5% for both as we entered production in World War II. As a means of conserving copper at the expense of zinc there was a proposal to lower the copper range three percentage points. There was no general agreement on this and some were opposed to the change. Certainly steel cases, then being developed, offered much greater savings; and the

mills and arsenals were established on volume production on brass with a 70% nominal copper.

The pros and cons were argued before the Metallurgical Advisory Board at Frankford Arsenal in July 1942. In August Army specification 57-172-1c was amended to give a copper range of 67.0 to 70.0%. Things did not go too smoothly and four months later the copper range was shifted back to the range of 68.5 to 71.5%, and there it stayed and there it is today and probably will continue.

Free Cutting Brass Rod—The specifications for free cutting brass rod and for forging brass had an interesting history. Both followed similar patterns and for purposes of illustration it will be sufficient to consider only the first. The principal specifications involved were A.S.T.M. B16 and Federal Specification QQ-B-611a, Composition B. Table I gives a few of the interesting details of the argument as to what could and should be done and what actually was done to the specification.

In the A.S.T.M. specification written in 1918, the iron maximum was set at 0.15% and the total elements other than copper, lead and zinc at 0.25% — in other words, a 0.10% total of impurities other than iron was permissible. That was really tight! In 1929 the A.S.T.M. changed the lead limits slightly and doubled the impurity limit (including iron) to 0.50% — that is, permissible impurities other than iron could now total 0.35% max. The Federal specification followed the A.S.T.M. limits and the American Standards Association added its endorsement to the specification which remained unchanged with respect to composition limits until 1942.

In the spring of 1942 these two proposals were made:

1. To increase the limit for impurities other than iron to 0.50% max., as the scrap used was becoming more contaminated.

2. To raise the impurities permitted to a total of 2.50%, including 1.00% nickel and 0.50% each of tin, iron, and "others".

No one could deny that it was desirable from the standpoint of better utilization of material to have available all the free cutting rod possible. There were however some unanswered questions in the minds of most materials engineers. How would the impurities affect the product — especially machinability — and how about

uniformity as between one lot low in impurities and another high? How necessary were the high limits and would they really open up a much larger supply? The first question was only partially answered and no clear answer was ever given to the last one.

It was claimed by the proponents of the second proposal mentioned above that the brass mills would soon be unable to continue to make free cutting rod unless these wide limits were permitted. When A.S.T.M. Committee B-5 met in June 1942 the problem was discussed at length and the first proposal was adopted for B16-42,* and this standard has not since been changed.

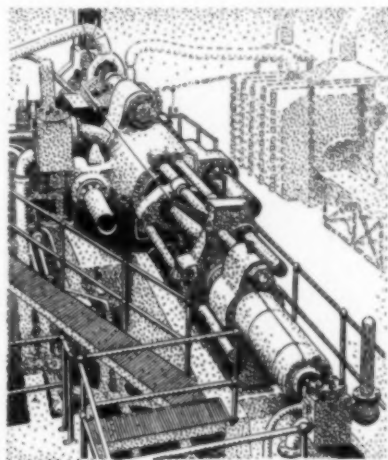
The proponents of the second proposal were not satisfied and carried the request for relief before the Metallurgical Advisory Board at Frankford Arsenal in July. As a result of the discussion there the Federal Committee in August adopted the A.S.T.M. B16 limits as of 1942 for QQ-B-611a, and wrote the other proposal with tin reduced to 0.30% max. into the emergency alternate E-QQ-B-611a.

As has been noted before, emergency alternates were not mandatory and, while the wide limits were on the books, it was rather a Pyrrhic victory for the proponents of the second proposal. It took some time for them to realize this but when they did (in the spring of 1943) there were requests again to

make the emergency limits the standard. A compromise was reached in revising the Federal specification with tin at 0.30%, iron at 0.35%, nickel 0.50%, "others" at 0.50% max., and this was written into an amendment to QQ-B-611a (and E-QQ-B-611a canceled) and into A.S.T.M. specification EA B16.

What of the future? We passed through a year of peak production in 1944. V-J Day has come and gone and there has been no further change. Nor has there been any move to change the composition of B16 or give EA B16 anything but an emergency status. That is the record to date. The supply of suitable scrap has not yet failed to provide adequate material for the regu-

*It is understood that in the numbering of A.S.T.M. specifications the first letter, as B, refers to the general type of metal (non-ferrous alloy), the subsequent figure to the serial number of specification, and the number after the hyphen the date at which the document in question was adopted.



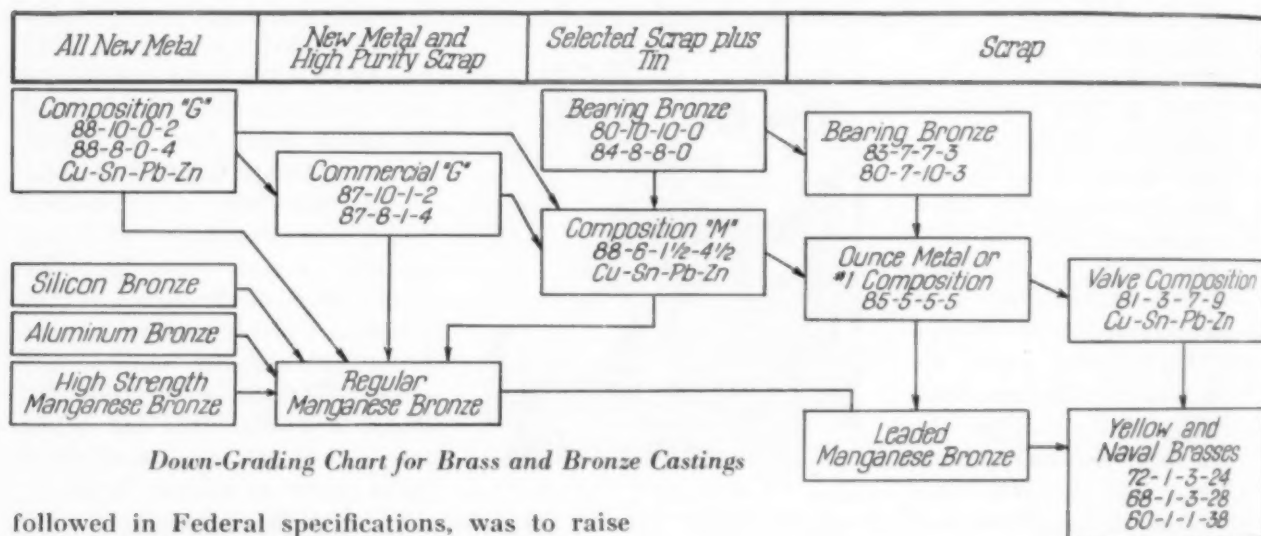
lar A.S.T.M. Standard B16. It seems safe to say it will stand for some time and the Federal specification may tighten up again to agree with it.

Copper-Base Alloy Castings and Ingot—It was noted in the opening remarks about copper that copper scrap was generally more available than primary metal in 1942. This copper scrap usually contained tin, so from the standpoint of better utilization of material (exceedingly critical tin, in this case) it was important to use it in the "as is" condition, if possible. This background was the basis for much active work in specifications and their use.

The first move, starting in 1941 and completed in the first half of 1942, was the development and promulgation of emergency alternate specifications for the commonly used bronze casting alloys. The emphasis in this group, developed by A.S.T.M. Committee B-5 and generally

Army and Navy programs and other more important uses for the copper and tin that would be required if bronze were used for such moderately stressed parts. The answer was a change in specification use. For land service malleable iron, galvanized, was adequate and for service where corrosion was more of a factor, yellow brass sufficed.

Down-Grading Chart—To visualize such changes in specification use, a down-grading chart for brass and bronze castings was developed and issued by the Conservation Division of War Production Board. It was issued first in January 1943 and was widely re-published. (See "Down-Grading Chart for Brasses and Bronzes," *Metal Progress*, March 1943.) This revised version, below, was issued in September 1943 when emphasis was placed on manganese bronze for which fired cartridge cases could be used. The



Down-Grading Chart for Brass and Bronze Castings

followed in Federal specifications, was to raise impurity limits, especially lead, to permit the better use of the available scrap. These emergency alternate specifications served a useful purpose in paving the way for future action, but like all others they were optional, and probably not too widely used. By mid-1942 it became apparent that even were they universally accepted and used, further conservation was needed. To use less primary copper and tin it was necessary not merely to modify specifications but to change to a different specification if possible. Again—Better Utilization of Material. Many items were being made of a high tin bronze requiring all new metal (or nearly so) when a yellow brass or even a ferrous metal would do.

Take, for example, fire hose couplings and nozzles. The "Underwriters Mixture" called for 83% min. copper, 5% min. tin, 3% max. lead and 7% max. zinc. There was no denying that it made excellent castings. But there were large

emphasis in the first edition of the down-grading chart was on specification changes to save primary copper and equivalent high-grade scrap. Tin conservation was included, of course, but was not then paramount. The maximum possible use of the non-ferrous scrap, then available, was desired so that primary copper and tin could be diverted to more important uses.

The Army, the Navy, the Maritime Commission, and industry in general cooperated in applying the idea that the chart visualized. Many design engineers used it to advantage. The savings in primary copper requirements in the casting field reflected its application, building up to over 5000 tons per month. In a nine-month period in which foundry output rose 17%, the new copper fed into the foundries and ingot makers decreased by 22%.

Standardization — It became apparent in 1943 that the maximum use of the down-grading chart would not secure the maximum savings possible, if various specifications for standard alloys differed in unimportant details. (Not long before the war one of our large ingot makers, on making a check of the subject, found that he was making the alloy known as 85-5-5-5 to 40 different prescriptions!) An effort to secure some kind of standardization was obviously the next step. Again, A.S.T.M. Committee B-5 took the lead in working out the program with active and full cooperation of members of the Federal Metals Committee representing Army and Navy interests. The Society of Automotive Engineers, the mechanical division of the Association of American Railroads and representatives of the Highway Engineers all took part in the work.

Several meetings were held and for each of the score or more alloys, most generally used, the Federal, A.S.T.M., Army, Navy, S.A.E. specifications (and emergency alternates) were compared. Agreement was reached, not always at the first try, on specification limits which all could accept for ingot metal and for the castings as well. The recommendations of these conferences were duly considered by each of the specification committees involved and each amended its own specifications during 1943 and 1944 to achieve a standardization that should carry on for some time to come.

Future of Down-Grading — Because of the tin situation it is necessary to continue the principle of down-grading. It is possibly too early, as yet, to estimate the future accurately. It is my belief, however, that alloys such as "G" and "Underwriters Mixture" will not resume their former importance, but will be replaced quite generally by "M" and 85-5-5-5. The 88-10-2 variety of "G" is already passing out in favor of the 88-8-4, which is the only one now recognized by Federal and Navy specifications.

Another trend which will result from the wartime impact on the non-ferrous casting field will be much wider acceptance of "ingot" metal. Before the war many foundries "mixed their own" from virgin metals. But when they could not get the primary copper and tin they learned to depend on alloy ingot, and will, I believe, continue to do so to a much greater extent.

Tin

Regular readers of *Metal Progress* will recall several articles on the tin shortage, especially "American Tin Supplies and Wartime Consumption" by Erwin Vogelsang in the December 1944

issue. If anyone intending to use tin now or in the immediate future has not read this article, he should do so and get a clear and accurate picture of the tin situation.

As that article shows, the fact that we have *any tin at all* today, and have not been forced to take even more drastic measures, was due to the foresight of those who built up our stockpile before the war and to the measures that were taken to reduce our tin consumption. The development of very thin electrolytic tin plate in a matter of months instead of years was an outstanding achievement of American industry. That, and the careful regulation of the types of cans to be used to package various products (the M-81 Order of WPB), accomplished a major saving in tin. The successful development and use by the can industry of fully automatic side seaming operations with a 2% tin alloy was another outstanding achievement.

Electrolytic tin plate for the can industry (possibly with slightly thicker coatings than at present) and the use of low tin solders by the can industry are wartime developments which, it seems safe to predict, are with us to stay.

Tin in Bronzes — Before the war use in bronzes was in fourth place as a consumer of tin, but only one-fourth of it came from primary metal, the rest from secondary and scrap. The tremendous wartime demand for copper alloy castings, particularly for the shipbuilding program of the Navy and Maritime Commission, doubled this demand, in spite of many effective conservation measures, chiefly by design change. (An outstanding example was the change from composition "G" to composition "M" for stern-tube bushings for the Maritime Commission ships, a change pioneered by the Navy.

During 1944 the tremendous demands for increased foundry output also tended to dry up the supply of tin in copper alloy scrap. For example, radiators from junked automobiles, with their large content of solder, were no longer in adequate supply to meet the demand. As a consequence the amount of new tin for bronze castings doubled in percentage also, so that four times as much primary tin had to be fed into the foundries from our dwindling stockpile. No wonder this field continues to be one of major concern, and emphasis is being placed on down-grading to lower tin content and design changes into the non-tin alloys such as yellow brass, silicon bronze, aluminum bronze, and manganese bronze. Such design changes are not easy. The properties of these tin-free alloys are in many ways different from the tin bronzes. Foundry practice is different. Patterns require greater

allowance for shrinkage. Alloys higher in zinc than a foundry is used to handling will lead to difficulty with zinc fumes. Moreover silicon and aluminum are "poison" to the tin bronzes, and foundry scrap must be carefully segregated.

Necessity is a hard taskmaster and American industry is resourceful. Reconversion that contemplates the use of copper alloys containing tin will have to learn to use the available substitutes, for a while at least. The cut-back in shipbuilding and other war programs will give a very large measure of relief. However, the best estimate is that it will be at least two years before the tin properties in the Far East are back in normal production again, even though the war is over.

What of the future? Undoubtedly some of the down-grading from high tin to lower tin bronzes, as from composition "G" to composition "M" or 85-5-5-5 will stay with us. Some of the

The war accelerated the development of low tin alloys and emergency alternate specifications were written to cover these by the Federal Specifications Board, the A.S.T.M. and the S.A.E. Some of these emergency grades did not work out too well and have been dropped. Others proved to be excellent substitutes, especially where the bearings could be redesigned.

Five grades of low tin babbitt, shown in Table II, are included in Federal Specification QQ-M-161a issued April 3, 1945 to supersede the 1932 specification and the 1942 emergency alternate. These lead-base babbitts are not as corrosion resistant as tin-base babbitts, and may not stand as hard pounding or as heavy pressure (unless, as noted above, thin bearings are used). Many important applications of these low tin babbitts could be cited. One that comes readily to mind was on the line shaft bearings of ships built by the Maritime Commission.

Table II — Chemical Compositions of Lead-Base Babbitts

GRADE	TIN	ANTIMONY	LEAD	COPPER	IRON (MAX.)	ARSENIC	ZINC (MAX.)	ALUMINUM (MAX.)	OTHER ELEMENTS (MAX.)
6	4.5 to 5.5	14 to 16	79 to 81	0 to 0.50	0.10	0 to 0.20	0.005	0.005	0.50
7	9 to 10	14 to 16	74 to 76	0 to 0.50	0.10	0 to 0.20	0.005	0.005	0.50
10	0.75 to 1.25	14.5 to 17.5	78 to 83	0.4 to 0.6	0.10	0.6 to 1.4	0.005	0.005	0.50
11	9 to 11	11.5 to 13.5	74 to 79	0.4 to 0.6	0.10	0 to 0.2	0.005	0.005	0.50
13*	4 to 6	8 to 10	83 to 88	0 to 0.5	0.10	0 to 0.2	0.005	0.005	0.75

*Grade 13 is used for railroad car journal bearing linings.

substitutions into silicon and manganese bronzes will probably stay also. While the impact of the war on our specification usage is by no means over so that we can readily discern trends in this field, it seems safe to say that many of the changes have come to stay.

Babbitt—Even before the necessity for tin conservation directed attention to them, lead-base babbitts were in wide general use. Railroad car journal bearings have used a babbitt with only 5% tin for many years. There were, however, many uses of tin-base babbitts where tin was wasted—where experience had shown that entirely satisfactory service can be obtained with low tin alloys. Redesign is often involved. A thin liner of lead-base babbitt can often carry the same load that a thicker tin-base babbitt will, but they are not always interchangeable. That fact is clearly recognized in War Production Board's Order M-43 on Tin where "repair, maintenance, or replacement" are recognized as valid reasons for exceptions in important applications to the general 12% max. tin permitted in babbitt.

There is little doubt in this author's mind that low tin babbitts have made a definite place for themselves in our economy and have come to stay. This is not to say that there will be no reversion to high tin babbitts when tin is again freely available. Here is definitely an instance where substitutes, first developed as emergency alternate specifications and with the good ones sifted out from the not-so-good, were written into basic specifications. Much credit is due the metallurgists and engineers of the principal babbitt manufacturers who helped in this development and furnished the designers with the needed information on which they, in turn, could make the substitutions. Much credit is due also to the design engineers for their cooperation in these important applications that have been a major factor in tin conservation.

Solder—Solder is another field in which the emergency specification procedure was invoked to develop and bring into use alloys that conserved tin. As in babbitt, there is plenty of credit due designers, specification writers and the labo-

ratory research men who contributed to a very worthwhile achievement in tin conservation. Especially praiseworthy are the men in the shops who have had to teach new techniques in the art of soldering, not only to new workmen, but — much more difficult — to the old-timers who knew the solder was “not what it used to be”.

It has always seemed to me that the 50-50 solder was a most fortuitous metallurgical accident, comparable only to the discovery of the lead alloy that makes a round shot when dropped down a shot tower. Back somewhere in the unrecorded history of the art, before eutectics and plastic ranges and other scientific approaches to the problem were known, someone melted equal weights of tin and lead and found he had produced an excellent solder.

While some applications of solder used a higher or lower tin content for some reason or another, the bulk of it was undoubtedly 50-50 when the war started. We have found, though, that we can get along very well with much less tin than that, although it has taken time and patience to get the facts established.

When the first conservation moves were made, the percentage of tin for “civilian applications” was rigidly restricted (a general 21% max. tin for unclassified uses). It was assumed that because any item was an “implement of war” it was entitled to exemption from any restriction as to the solder that might be used.

That approach however did not conform to the idea we have mentioned of “Better Utilization of Material”, now generally recognized as the only sound approach to real conservation. When a user was accustomed to a 50-50 solder, the 20-80 just did not work. He therefore “appealed the order” with a very plausible story which was nearly always accepted. But he did not try any of the intermediate grades which might have been satisfactory — while he was appealing he went all the way.

What was needed (and still is) was *the minimum use of tin in solder*. The revision of WPB’s M-43 order in 1944 was aimed at just that. The blanket exemption for “implements of war” was canceled. A realistic schedule of uses of different grades was worked out that could be followed by industry as well as the armed services.

Take automobile radiators for an example. The radiator manufacturing plants in mid-1944 were working about three-quarters of capacity on military items and the rest on civilian. The military radiators were using high tin solder, the civilian (with great difficulty and a definitely inferior product) low tin. Dipping operations could use low tin but such alloys were very unsatisfactory for hand soldering. The revised order established an average tin content of 21% for solder for cellular-type radiators and 32% for all fin-and-tube-type radiators for both military and civilian use. The lower tin used for

Buick Engine Bearings, Made by Moraine Products Division, General Motors Corp.



dipping averaged with the higher tin solders for hand work — treating military and civilian radiators alike — smoothed out manufacturing difficulties; a satisfactory product resulted at a net saving of about 10% of the tin allocated to this industry.

The use of a 2% tin solder by the can industry has already been mentioned. Realistic minima for each class of soldering operations were worked out with many industries, and definite savings were made all along the line. When the need for restrictions is removed it seems certain that many of the lower tin solders will continue to be used.

What of specifications in this field? Progress has not been as far as in the babbitts. Emergency alternate specifications were developed but the transition from their "emergency" to "standard" status has not been completed. Certain trends seem to be evident though and it would seem safe to predict:

1. The lower antimony, bismuth and other impurity limits of the Grade A solder compared with Grade B (as for example in A.S.T.M. Specifications B32-40T) will be a wartime casualty. Experience has shown they are not needed.

2. Solders containing antimony will be more widely used, as they are in England. In most applications antimony has beneficial properties in the lower tin alloys.

3. The lead-silver solders, such as 97½-2½, have not proven their worth and probably will be dropped.

4. The tin-antimony solders, such as 95-5, will not regain their prewar popularity. (The refrigerator trade may dispute that statement.)

Zinc

Zinc, even before Pearl Harbor, was in far greater demand than could be supplied. In 1941 and into early 1942, it was really tighter than copper. To make zinc available for cartridge brass and other important items, drastic restrictions were imposed on galvanizing, and many specifications were changed to eliminate its use. Actually the move that brought zinc into balance was not so much the restrictions imposed in the zinc orders, but the restrictions on the use of steel in Order M-126 of the War Production Board which prohibited the manufacture of many items that would have required galvanizing.

These changes and restrictions were temporary and have been canceled. In fact for the last two years or so zinc has been used, especially in die castings, as a substitute for other materials. This brings us to the consideration of the changes

that were made in the standard specifications for zinc die castings. Since this matter will be treated at length in the article by David Basch, only a short outline will now be presented.

During the early part of the war, when aluminum was in very short supply, there was an attempt made to cut the 4% nominal aluminum content of zinc-base die castings to 2%, and a restriction to this effect was written into the aluminum order by the War Production Board. Emergency alternate specifications were written in the spring of 1942 lowering the aluminum to 1.75% min. Later the restrictions in the aluminum order were changed to permit the 4% alloy, provided secondary aluminum were used. Most of the secondary aluminum available was of the duralumin type, containing about 4% copper, so if 4% aluminum from such a source were alloyed with pure zinc the resulting die casting would contain 0.16% copper. However, the specification limit for one of the principal alloys used is 0.10% copper max. Again the emergency alternate procedure was adopted to write specifications permitting this alloy to have 0.25% max. copper.

However, neither of these emergency alternate specifications was mandatory, and the controlling order had an "implements of war" escape clause. There was also the avenue of appeal. Just how much of the emergency alternate grades was actually used this writer does not know.

He does know that some material not conforming to the regular standard alloys definitely failed. The composition and impurity limits of the prewar alloys were established by the A.S.T.M. after a very comprehensive series of tests, extending over many years. Specification requirements based on known facts cannot be lightly tossed aside.

The fact remains also that when the restriction to the use of secondary metal was canceled in 1944, cancellation of the emergency alternate provisions followed promptly. It does not seem likely that they will be revived in the near future.

Conclusions

In each of the non-ferrous metals the stress of war has resulted in changes in specifications and in the specifying of materials. Much of it has been constructive and indications are that most of these changes will be retained. Some of the changes, or the restrictions imposed, were not too good. Like the house built on sand, they were soon washed away. The good has been retained and the bad discarded. On the whole the changes have definitely been on the credit side of the ledger; progress has been made. ●

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Corrosion Resistance of the Stainless Steels

IN ANY DISCUSSION such as this it is well to start with a few definitions:

Stainless steels are iron alloys containing sufficient chromium to produce the corrosion phenomenon commonly known as "passivity". The chromium limits of customary alloys are 11 to 30%, and include the Fe-Cr alloys constituting the hardenable *martensitic* (11 to 17% Cr) grades, and the non-hardenable *ferritic* (17 to 30% Cr) grades, the arbitrary boundary near 17% varying somewhat, depending upon the carbon and other alloy content.

To these iron-chromium alloys, 7 to 20% nickel is commonly added to produce the *austenitic* grades. Further additions of alloying elements, such as molybdenum, copper, silicon, titanium and columbium, provide modifications whose usefulness will be described later. For a comprehensive description of the physical characteristics of these steels, the Rustless Iron and Steel Corp.'s recent publication "Heat Treatment of Stainless Steels" is recommended.

To facilitate designation of the various alloys, American Iron and Steel Institute's type numbers will be used for wrought stainless steels as listed

*The writer wishes to express his appreciation to M. G. Fontana of the Du Pont Experimental Station for his helpful suggestions in compiling the material for this paper. Also to *Chemical and Metallurgical Engineering* for much of the data contained in the appendix, in much expanded form beyond that published in that journal.

in Table I. Although principal attention will be paid the wrought alloys, cast stainless steels will also be considered, whose designations set by the Alloy Casting Institute appear in Table II. With but few exceptions, all commercial products with their numerous nomenclature fall within these specifications. (Tables are on the next two pages.)

Passivity is a phenomenon producing very low corrosion rates in metals and alloys in spite of their thermodynamic potential to react and combine with their surroundings (liquid or gaseous). Passivity is not a condition of non-corrosion, but of negligible corrosion. The greatest passivity and passivity-conferring properties

appear in the sub-group VI-B metals of the periodic table of chemical elements, namely, chromium, molybdenum and tungsten, with lesser effects shown by the elements cobalt, nickel, vanadium, tantalum, iridium and rhodium in neighboring sub-groups. In iron-chromium alloys, passivity commonly occurs at 11.5 to 15% chromium, depending upon factors to be discussed.

An attractive theory is that passivation occurs when a favorable electron redistribution takes place in the inner electron "shells" upon alloying; but the constant association of passivity with oxidizing conditions, either fundamental to passivity or merely coincidental with it, makes another theory, the theory that an "oxide film" is produced, not only popular but useful.

Generalization — For purposes of orientation, several broad statements can be made regarding stainless steels and corrosion resistance:

1. The utility of these steels virtually depends upon the attainment of passivity.
2. Chromium is the basic alloy addition for attaining passivity.
3. With increasing chromium content, corrosion resistance generally increases.
4. Since passivity attends chemically oxidizing conditions, (a) strongly reducing media, such as HCl and HF, cause liability to attack; (b) oxidizing media cause supernormal resistance to attack and (c) media of intermediate oxidizing ability create borderline cases.
5. The negative chlorine is characteristically destructive to the chromium steels.
6. Nickel as an alloying addition is next

Table I—Wrought Stainless Steels
(American Iron and Steel Institute Designations)

TYPE No.	CARBON	CHROMIUM	NICKEL	OTHER ELEMENTS*
301	0.08-0.20	16.0-18.0	6.0- 8.0	
302	0.08-0.20	17.0-19.0	8.0-10.0	
302-B	0.08-0.20	17.0-19.0	8.0-10.0	Si 2.00-3.00 {P or S or Se 0.07 min. Mo or Zr 0.60 max.
303	0.20 max.	17.0-19.0	8.0-10.0	
304	0.08 max.	18.0-20.0	8.0-10.0	
308	0.08 max.	19.0-21.0	10.0-12.0	
309	0.20 max.	22.0-24.0	12.0-15.0	
310	0.25 max.	24.0-26.0	19.0-22.0	Si 1.50 max. Mo 1.75-2.50
316	0.10 max.	16.0-18.0	10.0-14.0	Ti is 4 × Carbon (min.) Cb is 8 × Carbon (min.)
321	0.10 max.	17.0-19.0	8.0-11.0	Turbine quality Al 0.10-0.30 Al 3.50-4.50
347	0.10 max.	17.0-19.0	9.0-12.0	
403	0.15 max.	11.5-13.0		
405	0.08 max.	11.5-13.5		
406	0.15 max.	12.0-14.0		
410	0.15 max.	11.5-13.5		
414	0.15 max.	11.5-13.5	1.25-2.50	
416	0.15 max.	12.0-14.0		{P or S or Se 0.07 min. Mo or Zr 0.60 max.
420	Over 0.15	12.0-14.0		
430	0.12 max.	14.0-18.0		
430-F	0.12 max.	14.0-18.0		{P or S or Se 0.07 min. Mo or Zr 0.60 max.
431	0.20 max.	15.0-17.0	1.25-2.50	
440-A	0.60-0.75	16.0-18.0		
440-B	0.75-0.95	16.0-18.0		
440-C	0.95-1.20	16.0-18.0		
442	0.35 max.	18.0-23.0		
443	0.20 max.	18.0-23.0		
446	0.35 max.	23.0-27.0		Cu 0.90-1.25
501	Over 0.10	4.0- 6.0		
502	0.10 max.	4.0- 6.0		

*Manganese — 2.00 max. in all 300 types
Manganese — 1.00 max. in all 400 and 500 types
Silicon — 1.00 max. in all types except 302-B and 310
Phosphorus — 0.04 max. in all types except 303, 416 and 430-F
Sulphur — 0.04 max. in all types except 303, 416 and 430-F

to chromium in importance, generally improving the engineering properties and, in alloys properly heat treated, improving specifically the corrosion resistance in neutral chloride solutions and in acids of low oxidizing capacity.

7. Molybdenum, with certain exceptions, expands the passivity range and improves corrosion resistance, particularly in sulphuric and sulphurous acids at high temperatures and pressures and in neutral chloride solutions, including sea water.

8. Copper additions have a restricted usefulness, giving protection particularly in sulphuric acid service.

9. Intergranular attack of the austenitic iron-chromium-nickel alloys is one of the foremost corrosion characteristics of these steels. It is avoided by proper heat treatment, or by alloying with columbium or titanium.

In the text to follow, these generalities are broadened; and in the Appendix specific corrosion values are listed for the various alloys.

Effect of Condition of the Steel

Fe-Cr Alloys (A.I.S.I. 400 Series)

— Hardenable Fe-Cr alloys are generally selected for engineering properties rather than for corrosion resistance. Least attack is experienced in quenched alloys, corrosion resistance decreasing with further heat treatment beyond a low temperature draw, concurrent with precipitation and growth of carbides.

In chemical plant service, Type 430 is often used on the low chromium side (15 to 16%) to gain some improvement in engineering properties without noticeable sacrifice of corrosion resistance. This type of alloy is only slightly hardenable and is best prepared by soaking at 1400 to 1450° F. and slow cooling (<100°/hr.) to 1100°. Bars are sometimes quenched from 1450° F., but fabricated equipment is more often slowly cooled. With laboratory specimens, quenching produces slightly better corrosion resistance than air cooling, but that advantage is not necessarily under plant conditions. Quenching from temperatures above 1450° F. is injurious, for beginning about 1500° a carbide structure forms which is unfavorable to corrosion resistance. Double heat treatment employing a preliminary short anneal at 1850° is sometimes advised for securing greater toughness. At high temperatures, grain growth may occur,

but with no appreciable effect on corrosion resistance.

The high chromium alloy Type 446 is comparable to the austenitic alloys in corrosion resistance, but is often less desirable because it is difficult to weld.

Temper brittleness, resulting from treatment at temperatures between 800 and 1000° F., is a prominent phenomenon which slightly decreases the corrosion resistance. Also, a hard and brittle formation, known as the sigma phase, may develop in high chromium alloys and other steels of high total alloy content during prolonged heating. While theoretically important, corrosion failures are seldom traced to this sigma phase.

Fe-Cr-Ni Alloys (A.I.S.I. 300 Series) — To avoid intergranular failure of these austenitic alloys, they must not be heated at temperatures between 800 and 1400° F. or slowly cooled through

Table II — Cast Stainless Steels
(Alloy Casting Institute Designations)

TYPE No.	CARBON	CHROMIUM	NICKEL	OTHER ELEMENTS
CA-14	0.14 max.	11.0-14.0	1.0 max.	Mo 2.0 max.
CA-40	0.20-0.40	11.0-14.0	1.0 max.	
CB-30	0.30 max.	18.0-22.0	2.0 max.	
CC-35	0.35 max.	27.0-30.0	3.0 max.	
CD-10M	0.10 max.	27.0-30.0	3.0- 6.0	
CE-30	0.30 max.	27.0-30.0	8.0-11.0	
CF-7	0.07 max.	18.0-20.0	8.0-10.0	
CF-10	0.10 max.	18.0-20.0	8.0-10.0	
CF-16	0.16 max.	18.0-20.0	8.0-10.0	
CF-20	0.20 max.	18.0-20.0	8.0-10.0	
CF-7Se	0.07 max.	18.0-20.0	8.0-10.0	Se 0.20-0.35
CF-7C	0.07 max.	18.0-20.0	8.0-10.0	Cb 10×C
CF-7M	0.07 max.	18.0-20.0	8.0-10.0	Mo 2.5-3.5
CF-10M	0.10 max.	18.0-20.0	8.0-10.0	Mo 2.5-3.5
CF-16M	0.16 max.	18.0-20.0	8.0-10.0	Mo 2.5-3.5
CF-7MC	0.07 max.	18.0-20.0	8.0-10.0	{ Mo 2.5-3.5 Cb 10×C
CG-7	0.07 max.	20.0-22.0	10.0-12.0	Se 0.20-0.35
CG-10	0.10 max.	20.0-22.0	10.0-12.0	
CG-16	0.16 max.	20.0-22.0	10.0-12.0	
CG-16Se	0.16 max.	20.0-22.0	10.0-12.0	
CG-7C	0.07 max.	20.0-22.0	10.0-12.0	
CG-7M	0.07 max.	20.0-22.0	10.0-12.0	
CG-10M	0.10 max.	20.0-22.0	10.0-12.0	
CG-16M	0.16 max.	20.0-22.0	10.0-12.0	
CG-7MC	0.07 max.	20.0-22.0	10.0-12.0	
CH-10	0.10 max.	23.0-26.0	10.0-12.0	
CH-20	0.20 max.	23.0-26.0	10.0-12.0	Cb 10×C
CH-10C	0.10 max.	23.0-26.0	10.0-12.0	
CH-10M	0.10 max.	23.0-26.0	10.0-12.0	
CH-20M	0.20 max.	23.0-26.0	10.0-12.0	
CH-10MC	0.10 max.	23.0-26.0	10.0-12.0	
CK-25	0.25 max.	23.0-26.0	19.0-21.0	
CM-25	0.25 max.	8.0-11.0	19.0-21.0	
CN-25	0.25 max.	18.0-22.0	23.0-26.0	
CS-25	0.25 max.	8.0-12.0	29.0-32.0	
CT-25	0.25 max.	13.0-17.0	34.0-37.0	

that range. At those temperatures carbides precipitate in the grain boundaries, presumably depleting the adjacent chromium content and thereby destroying the corrosion resistance of that film. While there is still dispute over the exact nature of this phenomenon of "sensitivity", there is complete agreement on the results. For example, Type 304 quenched from 1800° F. showed an attack in boiling 65% HNO₃ of 0.012 in./yr., but as much as 5.6 in./yr. when subsequently drawn at 1200° F. Tested in Strauss solution (CuSO₄ and H₂SO₄), improperly heated 304 may totally disintegrate in a matter of hours.

These steels are therefore preferably water quenched from 1900 to 2100° F., the high temperature putting any carbides already present in solution and the rapid cool preventing their re-appearance. Typical furnacing times are:

SECTION THICKNESS	MINIMUM TIME
< 1/8 in.	5 min.
1/8 to 1/4	15 min.
1/4 to 1/2	30 min.
1/2 to 1	1 hr.
> 1 in.	2 hr.

Too long soaking periods must also be avoided, since coarse grains aggravate sensitivity.

Extremely critical is the cooling rate, requiring attainment of black heat in less than 2 or 3 min., depending to some extent, of course, upon the severity of the corrosion conditions to which the metal will be exposed.

For some large or complicated plant equipment such heat treatment is impossible, and it then becomes necessary to use grades 321 and 347 which are austenites "stabilized" with titanium and columbium, respectively. The greater affinity of these two elements for carbon prevents chromium from precipitating in a carbide while the steel is in the critical temperature range of 800 to 1400° F., and the phenomenon of sensitization is thereby avoided. No special heat treatment is needed, beyond the 1850 to 2000° F. softening treatment for rolled plate, and the stress-relieving treatment at 1550° required for pressure vessels by the A.S.M.E. Boiler Code.

Figure 1 depicts these relationships among corrosion resistance, temperature, and stabilized and unstabilized 18-8. The degree of defection in unstabilized Cr-Ni steels depends upon temperature, time at temperature, and but little upon alloy content. With increasing carbon content, how-

ever, intergranular corrodibility increases as shown in Fig. 2.

A special "stabilizing" treatment at 1550 to 1650° F. after rolling is sometimes found advisable as an additional guarantee for full utility of titanium and columbium. In that temperature range a maximum amount of carbide forms with these two metals without yet entering the range where chromium carbide forms.

Some preference for Type 347 over 321 has been expressed, particularly on the basis of the degree of stabilization of annealed material in nitric acid; but under other conditions, other conclusions have been reached which prevent at this time stating a preference between the two grades. Neither columbium nor titanium in amounts added for stabilization changes measurably the basic corrosion resistance of the stainless steels.

For the higher alloy grades 308 to 310, the cooling rate may be even more critical, and heat treatment at $\approx 2100^\circ\text{F}$. is recommended. As a standard test for detecting sensitization, a boiling mixture of 10% H_2SO_4 and 10% CuSO_4 is used (the Strauss test), which is both strongly acid and strongly oxidizing. Failure to passivate in the presence of the CuSO_4 discloses susceptible areas to acid attack. Boiling 65% HNO_3 is similarly used, the standardized "Huey test" requiring five 48-hr. periods of immersion in boiling acid.

Grades Having Further Alloy Additions—Further alloy additions to stainless steels may improve them or harm them, depending upon many factors which must be cautiously evaluated. Molybdenum is especially advantageous for H_2SO_4 service, but is disadvantageous in HNO_3 service. This is illustrated by Fig. 3 for cast stainless steels of CF-M type. Molybdenum also decreases pitting in solutions containing chlorine ions. Copper increases markedly the resistance to H_2SO_4 , but has few other recommendations. In Type 442, for example, 1% copper allows the $\text{HNO}_3\text{:H}_2\text{SO}_4$ ratio of $2\frac{1}{2}\text{:}1$ (necessary for passivation) to be decreased to $<1\text{:}1$.

Silicon improves somewhat the resistance to strong H_2SO_4 , but has little effect on corrosion resistance to dilute acid, and is unfavorable in HNO_3 service. Manganese, which can replace nickel—according to certain foreign writers—has no outstanding advantage, an 18% Cr, 8% Mn steel having less corrosion resistance than an 18-4-4 having 4% of the manganese replaced with nickel. However, the manganese in 18-8 Cr-Mn does add to the corrosion resistance afforded by the chromium alone, and that grade is suitable for cold dilute HNO_3 , phosphoric, carbolic, lactic, and sulphurous acids and fruit juices. It is

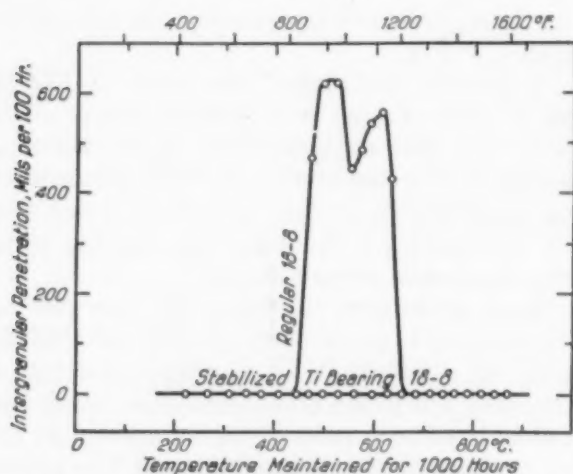


Fig. 1—Comparison of Corrosion Rates of 18-8 in $\text{CuSO}_4\text{-H}_2\text{SO}_4$ Solution, With and Without Stabilization by Titanium (Bain)

unsuitable for mine water, sea water, salt spray, sulphite liquors, and ferric chloride solutions.

In the free-machining grades, corrosion resistance is decreased slightly by sulphur, less by selenium.

Nitrogen, added to high chromium steels for grain refinement and to chromium-nickel steels as an austenitizing element (and often characteristically present in stainless steels because of its affinity for chromium) has lately been indicated to cause and contribute to sensitization in the austenitic steels. Under other conditions it has no particularly harmful effect, and the corrosion resistance of 25% Cr steel in boiling NH_4Cl is improved with the addition of nitrogen.

Surface Finish—Some slight advantage is often noted in polished over ground surfaces.

Cast vs. Wrought Alloys—Taking into consideration the difference in silicon content (and possibly unsoundness of castings), there is little distinction between the corrosion resistance of cast and wrought alloys.

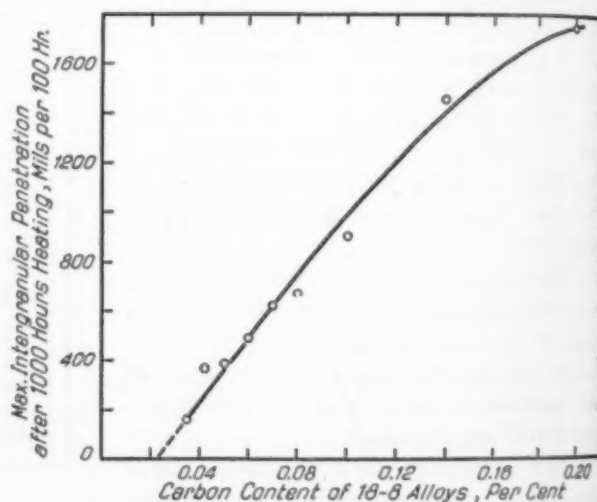


Fig. 2—Relation of Carbon in 18-8 to Intergranular Corrosion After Maximum Sensitization (Bain)

Resistance to Acids

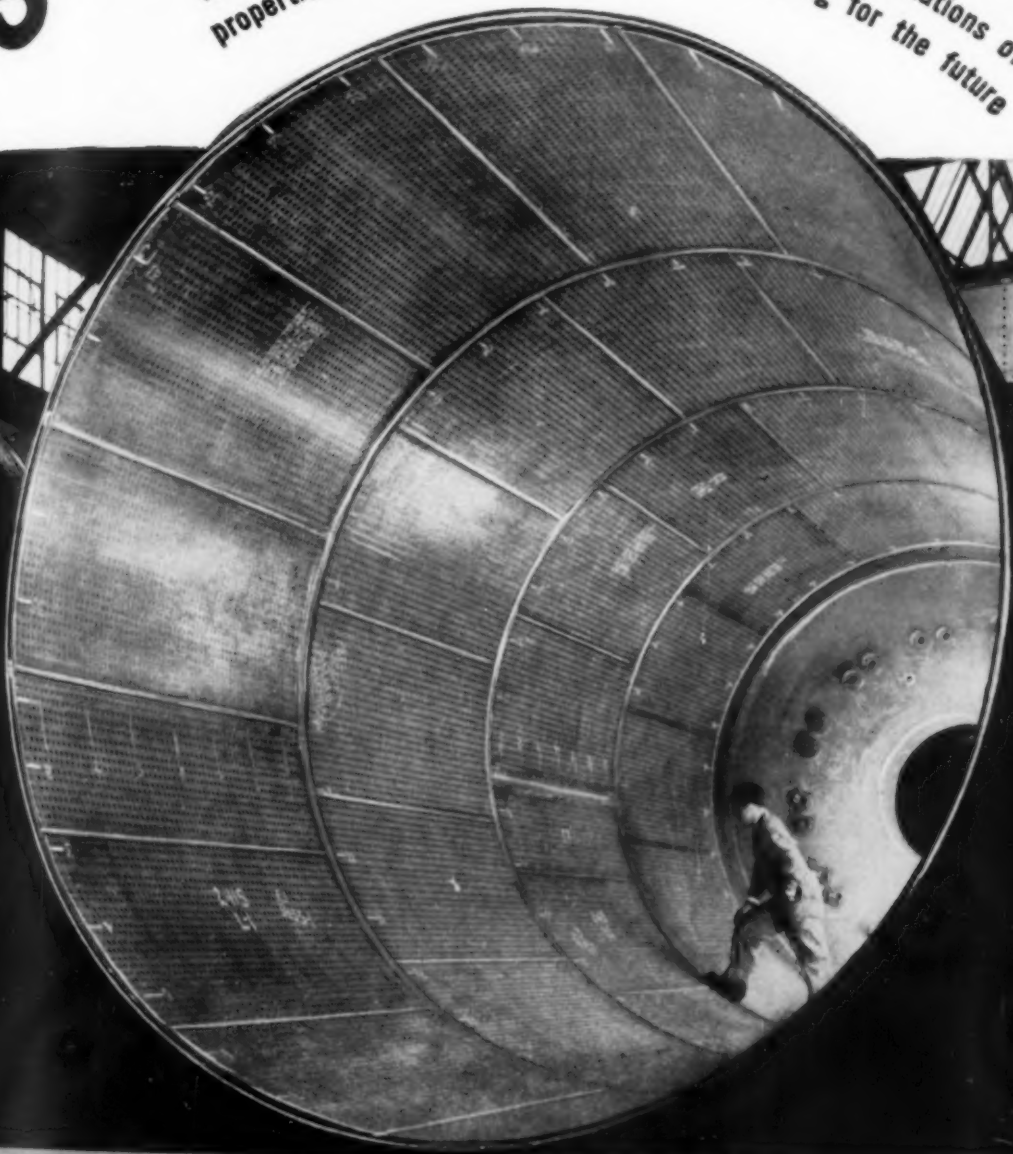
HCl and HF—Least oxidizing of the common acids, HCl and HF attack all stainless steels in all concentrations at all temperatures (with certain occasional exceptions found for HCl). Even aeration, which usually greatly aids the attainment of passivation, will not dependably produce passivity in HCl solutions $>1\%$. Furthermore, there is special danger of localized corrosion—pitting—whenever the chlorine ion is present.

The addition of molybdenum increases resistance to HCl, but the steels are still not to be recommended for use against such acid solutions.

H_2SO_4 —Borderline activity occurs in sul-

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The commonly used chromium-Nickel type stainless steel that lines this fractionating column possesses natural immunity to rust and corrosion under virtually all oxidizing-acid conditions. Its resistance to creep, scale or oxidation at high temperatures assures long economical operation. Built by A. O. Smith

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Transformation of S.A.E. 4315 During Continuous Cooling

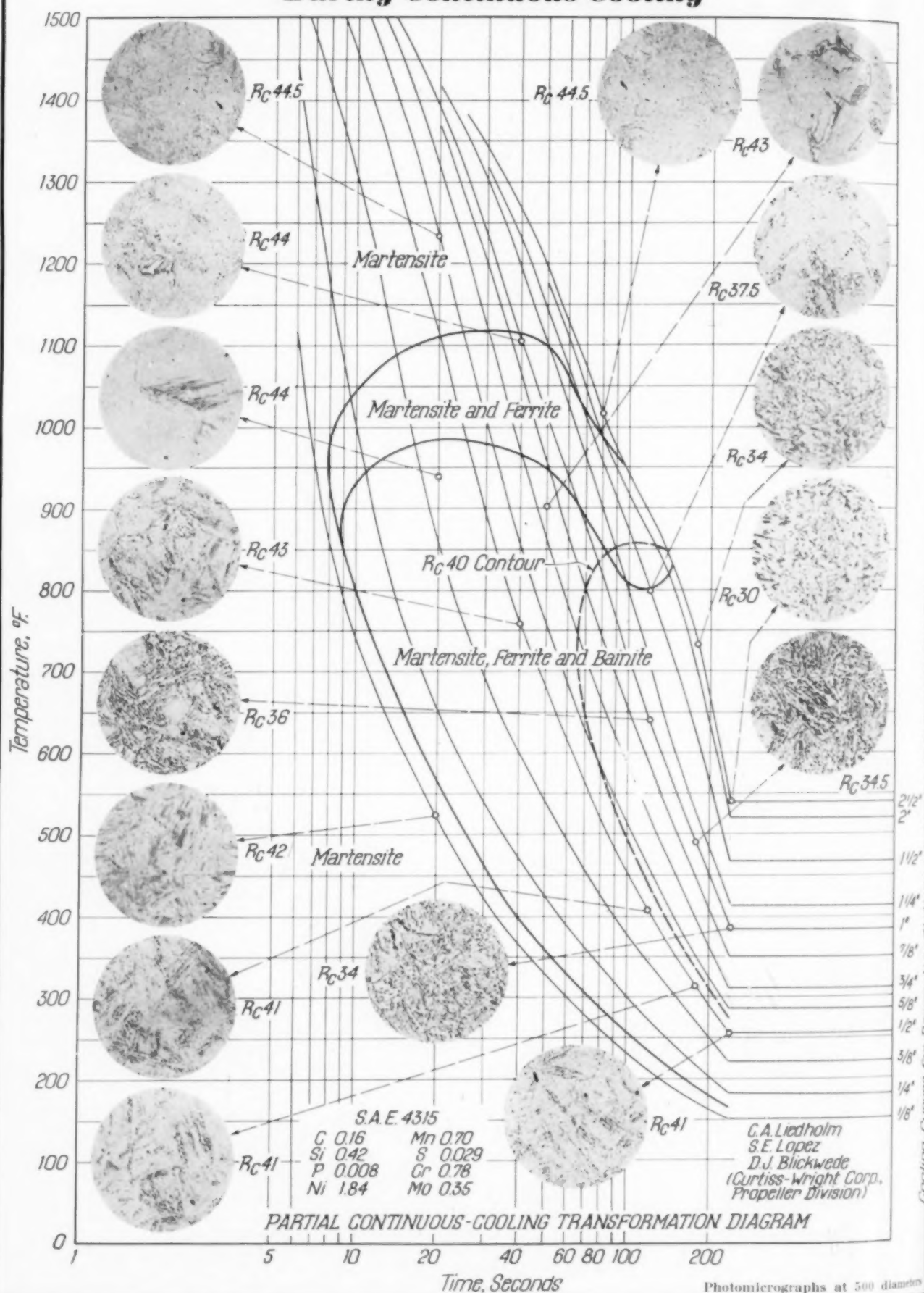
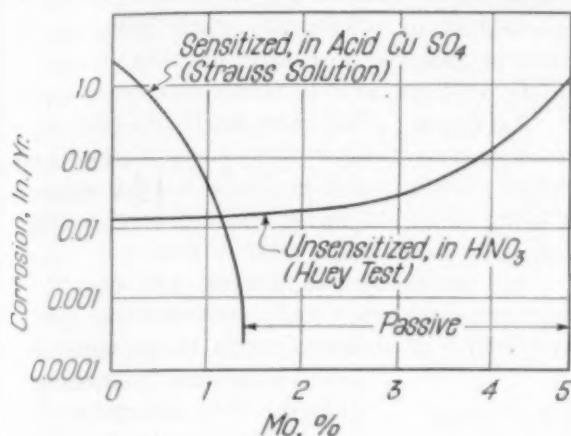


Fig. 3 -- Effect of Molybdenum on Cast Alloy (19% Cr, 9% Ni, 0.09% C). Quenched, unsensitized alloy immersed five 48-hr. periods in boiling 65% HNO_3 (Huey test). Other samples were sensitized by holding 24 hr. at 1200° F., then tested in Strauss solution (boiling 10% $\text{CuSO}_4\text{-H}_2\text{SO}_4$) for 72 hr. From Bulletin of the Alloy Casting Institute



phuric acid, making recommendations conditional and subject to cautious study.

Unlike lead, which is more resistant to H_2SO_4 when the solutions are dilute, stainless steels resist that acid when it is concentrated, as do also the plain steels. Rates of 0.0002 in./yr. are obtained with Type 304 at room temperature; however, the rate rises rapidly with temperature. Maximum corrosion resistance occurs at intermediate acid concentrations, and in dilute solutions conditions of activity or passivity may be uncontrollably interchangeable.

For example, boiling H_2SO_4 up to 0.02% may passivate Type 309 and give it a corrosion rate <0.0002 in./yr., whereas concentrations >0.05% may activate the steel and cause rates of 0.04 in./yr. (See McKay and Worthington, "Corrosion Resistance of Metals and Alloys", p. 286.) Again, 3% H_2SO_4 corroded Type 304 at a rate >0.8 in./yr. with hydrogen bubbling through it, but at only 0.008 in./yr. when oxygen was bubbled through. Strongly aerated H_2SO_4 concentrations of 1 to 15% will generally produce passivity. On the other hand, thoroughly activated and aerated 5% H_2SO_4 failed in one reported

instance to develop passivity on either chromium or chromium-nickel alloys containing up to 32% Cr. It should also be mentioned that laboratory results showing passivity often do not reproduce themselves in plant service and must therefore be accepted with caution.

Nickel improves corrosion resistance in sulphuric acid service, and molybdenum further improves it, and especially useful are additions of oxidizing agents to the acid, such as cupric and ferric sulphate, sodium dichromate, and nitric acid. Figure 4 illustrates the strong passivating effect of ferric sulphate.

In Fig. 5, the relationship of chromium content to CuSO_4 as an acid addition shows the cooperation of these two factors in passivation.

H_2SO_3 —With the chromium content in the higher ranges, passivity is characteristic of service in sulphurous acid. Nickel somewhat lowers the chromium limit required for passivity, and Type 300 series alloys, particularly 316 and 317, are widely used in equipment handling the sulphurous acid solutions for sulphite digestion in the paper industry. Those steels, wrought or cast, have almost unlimited life, though sensitization must be carefully guarded against. Grades containing molybdenum are to be recommended for handling extremely hot saturated H_2SO_3 .

Sulphuric acid or chlorine ion in sulphurous acid may contract the passivity limits, on one occasion a corrosion rate of 4 ft./yr. having been observed for 28% Cr steel in a 5% H_2SO_3 solution containing 5% NaCl.

HNO_3 —Because of the oxidizing propensities of HNO_3 , stainless steel finds special usefulness in that medium, even with chromium contents less than the customary lower limit of 11 to 12%.

Rates are typically <0.02 in./yr., but are generally higher in the dilute (1 to 20%) range, averaging 0.06 to 0.08 in./yr.

Again, the austenitic grades are better than the ferritic, though the chromium steels can be recommended for nitric acid, nitrates, and mixed acids having $\text{HNO}_3\text{:H}_2\text{SO}_4$ ratios >2. Only for concentrated and hot solutions are the austenitic grades warranted, aside from engineering considerations. Units requiring field welding are advisably constructed of aus-

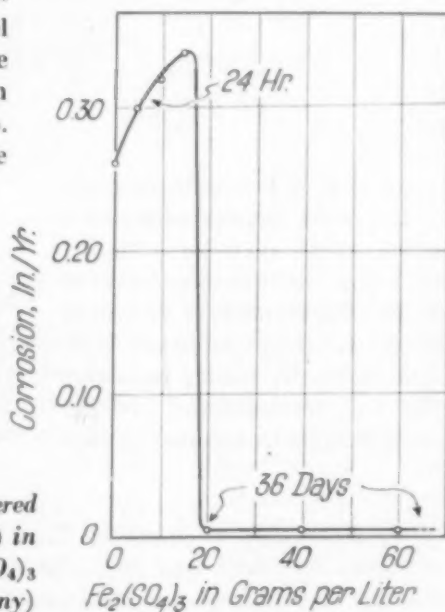


Fig. 4 — Hardened and Tempered Type 420 (12.6% Cr, 0.3% C) in 10% H_2SO_4 Containing $\text{Fe}_2(\text{SO}_4)_3$ as an Oxidizer (Monypenny)

tenitic rather than ferritic steel, and preferably stabilized.

As mentioned in discussing Fig. 3, molybdenum is slightly detrimental in nitric acid service. Silicon is also detrimental, and the 2% nickel in Type 431 is unfavorable. HNO_3 carrying chlorides or other halides (present in acid made from saltpeter) is corrosive to stainless steels.

Acetic Acid — Austenitic grades are especially serviceable in acetic acid, alloys containing molybdenum again being recommended for high concentrations and high temperatures. Early high corrosion rates may occur under severe conditions, but passivation soon slows the attack. For strong acetic acid of any concentration, at moderate temperatures, 18-8 is entirely satisfactory, though it must either contain a stabilizing element, if welded, or be properly heat treated. No important choice stands between these two conditions. The presence of oxygen dissolved from the air is an important factor in increasing the tendency toward passivity, though exceptions occur in which aeration and even the addition of oxidizers may accelerate corrosion, as with Type 316 in acetic acid containing organic materials.

Other Acids — In such acids as tartaric, formic, and phosphoric of <0.1%, dissolved oxygen from free exposure to air is often sufficient to cause passivity. In the absence of free oxygen, or in the presence of reducing agents, these media may be corrosive. Oxidizers such as ferric and cupric salts are again especially beneficial. If the oxidizing capacity fails to attain passivity, however, the oxygen becomes an accelerant of corrosion. Passivity may also be lost with increasing temperature, probably by decreased oxygen solubility.

Generally speaking, organic acids such as carbolic, lactic, malic, butyric, oleic or oxalic behave similarly to acetic acid and the other acids just mentioned. Chromium steels usually passivate readily in the range of lower temperatures and higher chromium contents, losing passivity toward the boiling point of the various solutions. Nickel and molybdenum again serve beneficially in enhancing passivity in the extreme conditions.

Fig. 6 — Effect of Nickel in 15% Cr Base Alloy on Attack by Thoroughly Agitated and Aerated Sea Water, 5% NaCl, and 20% CaCl_2 Solutions During a 20-Hr. Test at 86° F. (Pilling and Ackerman)

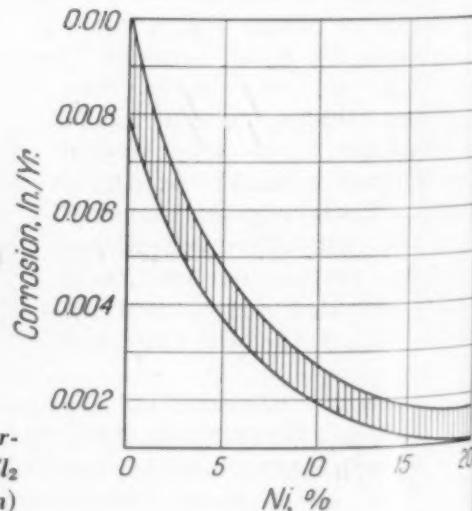
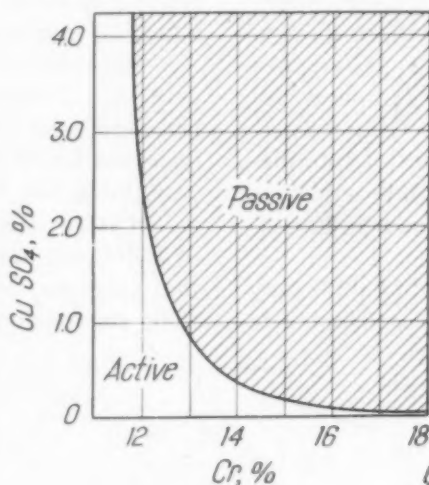


Fig. 5 — Relationship Between Chromium Content in the Cr-Fe Alloy and the Amount of Oxidizing Agent (CuSO_4 Added to 25% H_2SO_4 at Room Temperature) Necessary to Cause Passivation



Resistance to Strong Bases and Other Media

Caustic — At room temperature, ordinary steels resist caustic soda or potash solutions of any concentration as well as stainless steels, and at elevated temperatures they may resist it better. Nickel helps some, and at elevated temperatures at high concentrations a borderline condition may be reached in which the steels become either active or passive. For valve parts in contact with caustic fusions, 18-8 is sometimes recommended.

Ammonia — Ordinary steels are widely used in ammonia service, but stainless steels are completely resistant and have the further advantage of being rustproof under moist neutral conditions. Corrosion rates are <0.002 in./yr.

Salt Solutions and Waters — When salt solutions are reasonably well exposed to air, complete passivation of stainless steels is common. How-

ever, solutions containing the chlorine ion always present a special problem because of their preferential or pitting attack on steels containing chromium. Even in neutral solutions a constant danger exists, the occurrence of passivity being conditional. One investigator reports finding a potential intermediate between activity and passivity persisting for 50 hr. with Type 304 steel immersed in an aerated salt solution of high concentration.

Also, even with a given satisfactory oxidizing capacity, that capacity must be maintained or activation may occur. This introduces the principal problem, for there is no guarantee

Table III—Position of Stainless Steels in the Electromotive Series

From *Steel*, Jan. 22, 1945.

ANODIC END	
Magnesium	
Magnesium alloys	
Zinc	
Aluminum 2S	
Cadmium	
Aluminum 17ST	
Carbon steel	
Copper steel	
Cast iron	
4-6% Cr steel	
A { 12-14% Cr steel	Active
16-18% Cr steel	
23-30% Cr steel	
Ni-Resist	
7 Ni-17% Cr steel	Active
8 Ni-18% Cr steel	
B { 14 Ni-23% Cr steel	
20 Ni-25% Cr steel	
12 Ni-18% Cr-3% Mo steel	
Lead-tin solder	
Lead	
Tin	
Nickel	
C { 60 Ni-15% Cr	Active
Inconel	
80 Ni-20% Cr	
Brasses	
Copper	
Bronzes	
Nickel silver	
Copper-nickel	
Monel	
Nickel	
C { 60 Ni-15% Cr	Passive
Inconel	
80 Ni-20% Cr	
12-14% Cr steel	Passive
16-18% Cr steel	
7 Ni-17% Cr steel	
8 Ni-18% Cr steel	
14 Ni-23% Cr steel	
A and B { 23-30% Cr steel	
20 Ni-25% Cr steel	
12 Ni-18% Cr-3% Mo steel	
Silver	
Graphite	
CATHODIC END	

H₂S in water solutions is well resisted by the stainless steels, though there is some evidence that passivity breaks down in boiling solutions.

Food Products—Stainless steels are characteristically passive in exposure to food products. Always negligible, corrosion rates often are <0.0002 in./yr. Welded zones may sometimes develop slight pitting or rusting, especially in solutions such as vinegar-salt and boiling sugar-salt mixtures. 18-8 is usually preferred over the plain chromium grades both for reasons of mechanical properties and stainlessness. For Type 430, rates of 0.001 to 0.012 in./yr. are reported in tomato, apple, lemon, and red grape juices.

Interestingly, boiling fruit juices, which contain malic, tartaric, citric, and other acids previously discussed, will not destroy passivity, as those commercial acids do, even for equivalent concentrations.

Atmospheres—Except for the precious metals, stainless steel stands alone in the ability to resist atmospheric corrosion. Ordinary atmospheres are resisted virtually completely. Marine atmospheres sometimes provide injury because of the presence of chlorine ion, and sulphurous industrial atmospheres may discolor

stainless steels to an important degree. Most frequently 18-8 is used for its general workability.

Straight chromium types are also useful. Although the high chromium are best, Type 410 can be used in moderately corrosive atmospheres. As the atmosphere contains more and more sulphur, Type 410 will show discoloration and fine pitting. Less corrosion will occur on pieces exposed to the wash of rain than those exposed only to atmospheric moisture, fog, and dust.

Surface condition makes but little difference,

Fig. 7—Breakdown of Passivity of Type 316 Under Conditions of Dynamic Flow of Sulphuric Acid Slurry (Fontana)

though under critical conditions, such as strongly sulphurous or saline atmospheres, a buffed surface is superior to a ground surface. A similar lack of importance can be attached to heat treatment, although Type 400 series alloys are slightly better when hardened than when annealed. As for Type 300 series alloys, very little difference is noted even whether the steel is sensitized or not.

Galvanic Corrosion

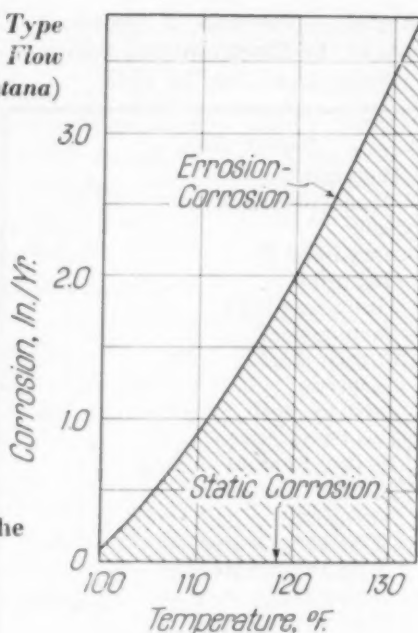
Galvanic potential is a fundamental consideration in corrosion studies, particularly of poly-phase alloys and systems involving bi-metal contacts. Consequently, in Table III certain of the stainless steels are grouped among the more common metals to depict the electrochemical status of stainless steels and the remarkable role of passivity in ennobling these alloys.

In the active condition, stainless steels are much like other steels electrochemically, and contact with other metals will accelerate attack. In solutions such as sea water, sodium sulphate, sulphurous acid, acetic acid, and concentrated NaCl, stainless steel in contact with other metals has caused galvanic attack—as expected from its electrochemical potential. (See Table III.)

On the other hand, in such media as milk it is known that the strongly cathodic nature of passivated stainless steels does not accelerate corrosion of bronze and other copper alloys, nickel or monel, or tin in contact with it, although aluminum, zinc and plain steel will corrode (but not as badly as when in contact with copper, for example). Also, contrary to expressed opinion, passivity can be destroyed by galvanic coupling.

As a first factor in galvanic corrosion, one can observe by its relative position in Table III which metal lies toward the anodic end from another and may therefore be expected to suffer galvanic corrosion.

The second important consideration is the ratio of area, anode to cathode, because the concentration of electrochemical transfer of metal from a comparatively minute anodic area is the cause of pitting. Even though two metals are closely placed in the table, a cathode surface can



be damaging simply through its relatively great size.

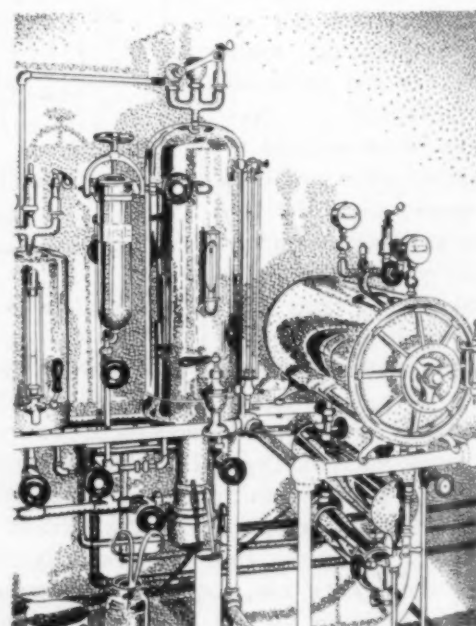
Erosion-Corrosion

Fontana, in the 1945 Transactions of the Electrochemical Society, called attention to the important role of erosion in accelerating corrosion in service and destroying passivation. Many of the differences obtaining between laboratory results and plant conditions employing mobile liquids are explained by his curve, Fig. 7.

Conclusion

To conclude this generalized and incomplete discussion with useful and detailed data, an extensive appendix has been compiled from the excellent presentation in *Chemical and Metallurgical Engineering* 11th Report on "Materials of Construction for Chemical Engineering Equipment" (Sept. 1944), and from F. Ritter's "Korrosionstabellen metallischer Werkstoffe" (1937).

The reader is referred to these sources for the further information they contain, to McKay and Worthington's "Corrosion Resistance of Metals and Alloys", to Thum's "The Book of Stainless Steels", to Monypenny's "Stainless Iron and Steel", and to Kinzel and Franks' two-volume work on "Alloys of Iron and Chromium".



Corrosion Resistance of the Stainless Steels in Wrought and Cast Form

Especially valuable data for these tables were secured through the kindness of M. G. Fontana of Du Pont Experimental Station and the Editors of *Chemical and Metallurgical Engineering*

	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./Yr., °F.)
	Acetic Acid	
	10-80%	<0.0042 at 70-180°
	10-60%	0.042-0.12 at b.
	90% aerated	0.042-0.12 at 180°
	80%	0.12-0.24 at b.
	100%	<0.0042 from 70-180°
	100%	0.042-0.12 at b.
	100% at 150 psi.	>0.12 at 400°
	3%	0.0047 at 70°, 0.000 at 180°
	20%	0.0043 at 70°, 0.000 at 180°
	40%	0.0216 at 70°, 0.0086 at 180°
	All	<0.0042 from 70-180°
	10-33%	<0.0042 at b.
	50-100%	0.0042-0.042 at b.
	100% sol. at 150 psi.	0.042-0.12 at 400°
	5-10% agitated	<0.0042 at 70°
	5-10% aerated	<0.0042 at 70°
	5%	>0.1 at 130°
	20% ag.	0.042-0.12 at 70°
	5%	0.00634 at 68°
	15%	0.00541 at 68°
	33%	0.00541 at 68°
	5% ag.	<0.0042 at 70°, 0.0042-0.042 at 100°
	10% ag.	<0.0042 at 70°
	15% ag.	>0.12 at 100°
	20%	<0.0042 at 70°
	33%, 60%	0.042-0.12 at 70°, 0.12-0.42 at 100°
	80%	0.0042-0.042 at 70°
		0.0042-0.042 at 100°
	100%	<0.0042 at 70°, <0.0042 at 100°
	10%	<0.0046 at 68° to b.
	50% - conc.	<0.0046 at 68°
	50% - conc.	<0.046 at 68°
CA-14	0.5%, 10%	*at 70°
CB-30	0.5%, 10%	*at 70°, *at b.
CB-30	Glacial	<0.001 at 95°, nil at b.
CC-35	0.5%, 10%	*at 70°, *at b.
	Glacial	nil at 95°, 0.031 at b.
CD-10M	0.5-100%	*at 70°, *at b.
CE-30	0.5-10%	*at 70°, *at b.
	80%	*at 70°
	Glacial	*at 70°, nil at 95°, 0.036 at b.
CF-7	0.5%, 10%	*at 70°, *at b.
	80%	*at 70°
	Glacial	<0.001 at 70°, 0.09 at b.
	Glacial	<0.001 at 95°, 0.09 at b.
CF-10		
CF-16		
CF-10M		
CF-16M		
CG-10		
CG-7C	0.5-100%	*at 70°, *at b.
CG-10M		
CG-16M		
CH-10M		
CF-7C	0.5%, 10%	*at 70°, *at b.
CF-7M	0.5-80%	*at 70°, *at b.
	100%	<0.001 at 70°, 0.003 at b.
CG-7		
CH-10	0.5-100%	*at 70°
CH-20	0.5%, 10%	*at 70°, *at b.
	80%	*at 70°
	Glacial	*at 70°, nil at 95°, 0.058 at b.
CH-20M	0.5-80%	*at 70°, *at b.
	100%	*at 70°, 0.0017 at b.
CK-25	0.5-100%	*at 70°
	Glacial	*at 70°, nil at 95°, 0.15 at b.

Abbreviations: *Recommended
 x Not recommended
 †Pitting may occur when allowed to dry, by condensation, or at the air-liquid level
 ‡Attack may occur if free acid is present
 b. Boiling liquid
 Conc. Concentrations or concentrated solution
 Sat. Saturated solution
 Sol. Solution

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./Yr., °F.)
	Acetic Anhydride	
302	90%	<0.0042 at 70°, <0.0042 at b.
	90% aerated	>0.12 at 180°
	60%	0.0042-0.042 at 180°
	30%	>0.12 at 180°
	Commercial	<0.003 at 70°
304		<0.004 at b.
304-347	Commercial	<0.003 at 70°
316	90%	<0.0042 at 70°, <0.0042 at b.
	90% aerated	0.042-0.12 at 180°
	30%, 60%	0.0042-0.042 at 180°
403	Commercial	<0.030 at 70°
410	Commercial	<0.030 at 70°
	Pure	<0.0046 at 70°, <0.038 at b.
430	90%	<0.0042 at 70°, 0.042-0.12 at b.
	Pure	<0.0046 at 70°, <0.038 at b.
	Acetone	
302		<0.0042 at 70° to b.
304-347	Conc.	<0.003 at 70°
316		<0.0042 at 70° to b.
403, 410		
420-430 F		<0.040 at 70°
	Acetylene	
302	Conc.	<0.003 at 70°
304-347	Conc.	<0.003 at 70°
403, 410		<0.005 at 70°
430, 442	Commercial	<0.003 at 70°
	Alum	
302	2%, 10%	<0.0042† at 70°, <0.0042† at b.
	Sat., no H ₂ SO ₄	<0.0042† at 70°, 0.0042-0.042† at b.
304-347	Sat., no H ₂ SO ₄	<0.0042 at 70°
316	10%	<0.0044 at 70°, 0.0044 at b.
	Sat.	<0.044 at b.
403, 410	Sat.	<0.01 at 70°
430	2%	<0.0042† at 70°
	10%	0.0042-0.042† at 70°, 0.042-0.12† at b.
	Sat.	0.12-0.42† at b.
430 F	10%	<0.0046 at 70°, <0.0046 at b.
	Sat.	<0.0046 at b.
	Aluminum Chloride	
302	10%, 25%	0.12-0.42 at 70°
	Sat.	<0.003 at 70°†
304		x at 70°
	Sat.	<0.003 at 70°†
308		
309	Sat.	<0.003 at 70°†
310		
316	10%, 25%	0.042-0.12 at 70°
321, 347	Sat.	<0.003 at 70°†
403	Sat.	Attacked
410		
420		
430		x at 70°
430 F		
	Aluminum Sulphate	
302	5%	<0.0042† at 150°
	10% (sat.)	<0.0042† at 70°, 0.0042-0.042† at b.
304	10%	0.004 at 70°, 0.04 at b.
	Sat.	<0.004† at 70°
308-347	Sat.	<0.004† at 70°
316	5%	<0.0042 at 150°
	10% (sat.)	<0.0042 at 70°, <0.0042 at b.
403, 410	5%†	<0.0042 at 150°
420, 430	10% (sat.)†	0.12-0.42 at 70°, >0.42 at b.
430 F	10%	x at 70° and b.

Corrosion Resistance of the Stainless Steels in Wrought and Cast Form

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)	STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)	STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Ammonia			Ammonium Sulphate			Bromine		
302	Any conc.	<0.0042 at 70° to b.	302	1%, 5%, ag.	<0.0042 at 70°	301-442	Bromine water	Strong attack at 70°
	Anhydrous	<0.004 at 70°		10%	<0.0044 at 68°†			
	Gas	0.12-0.42 at hot		10%	0.0042-0.042 at b.†			
304-347	Anhydrous or sol.	<0.004 at 70°		Sat.	<0.004 at 70°			
316	Any conc.	<0.0042 to b.	304	10%	<0.040 at b.			
403, 410	Anhydrous	<0.004 at 70°		Sat.	<0.004 at 70°			
	Any conc.	<0.005 at 70°	308-347	Sat.	<0.004 at 70°			
	Gas	No attack at 68°						
430	Anhydrous	<0.004 at 70°	316	1%, 5%, ag.	<0.0042 at 70°			
	Any conc.	<0.0042 at 70° to b.		10%	<0.0042 at 70°-b.†			
430	Gas	0.12-0.42 at hot		Sat.	0.0042 at 70°-b.			
430 F, 431	Any conc.	<0.004 at 70°	403, 410	1%, 5%, ag.	0.0042-0.042 at 70°			
442	Anhydrous	<0.004 at 70°		10%	Slight attack at 70°			
	Any conc.	<0.004 at 70°		Sat.	<0.010 at 70°			
Ammonium Chloride			430	1%, 5%, ag.	<0.0042 at 70°			
302	1% sol., quiet, ag.†	<0.0042 at 70°		10%	<0.004 at 70°†			
	10%, 20% sol.†	<0.0042 at b.	430 F	Sol.	<0.0046 at 70°			
	28%, 50% sol.†	0.0042-0.042 at b.	442	10%	<0.004 at 70°†			
	Sat.†	<0.0044 at 212°						
	Sat.†	<0.004 at 70°						
303	50%	<0.04 at b.						
304-310	Sat.†	<0.004 at 70°						
316	1%, quiet, ag.	<0.0042 at 70°						
	10% - conc.†	<0.0042 at b.						
	Sat.	<0.004 at 70°						
321, 347	Sat.†	<0.004 at 70°						
403, 410	1%, quiet, ag.	<0.0042						
	Sat.	<0.004 at 70°						
430	1%, quiet, ag.†	<0.0042 at 70°						
	10%	<0.0456 at b.						
	25%	<0.0456 at b.						
	Sat.	<0.456 at b.						
430 F	10% - sat.	<0.00456 at b.						
	10%	<0.00456 at b.						
431	25%	<0.0456 at b.						
	Sat.	<0.456 at b.						
Ammonium Nitrate								
302	All, ag.	<0.0042 at 70°						
	Sat.	<0.0042 at b.						
304-347	Sat.	<0.004 at 70°						
304		<0.004 at 70°, b.						
316	All, ag.	<0.0042 at 70°						
	Sat.	<0.0042 at b.						
403, 410	All, ag.	<0.0042 at 70°						
	Sat.	<0.0042 at b.						
420		<0.004 at 70°, b.						
430, 430 F	All, ag.	<0.0042 at 70°						
	Sat.	<0.0042 at 70°, b.						
442	Sat.	<0.004 at 70°						
Ammonium Phosphate								
302, 304	5%	<0.0042 at 70°						
	Sat.	<0.004 at 70°						
308-347	Sat.	<0.004 at 70°						
316	5%	<0.004 at 70°						
403, 410	5%	<0.004 at 70°						
	Sat.	<0.005 at 70°						
420-430 F	5%	<0.004 at 70°						
442	5%	<0.004 at 70°						
Abbreviations:								
*Recommended								
x Not recommended								
†Pitting may occur when allowed to dry, by condensation, or at the air-liquid level								
‡Attack may occur if free acid is present								
ag. Agitated or aerated								
b. Boiling liquid								
Com. Commercial								
Conc. Concentrations or concentrated solution								
C.p. Chemically pure								
Sat. Saturated solution								
Sol. Solution								

Corrosion Resistance of the Stainless Steels in Wrought and Cast Form

STEEL CORRODENT AND CONCENTRATION CORROSION RATE (IN./YR., °F.)

Chlorine		
302	Dry gas	0.042-0.12 at 70°
	Moist gas	0.12-0.42 at 70°
	Gas	>0.42 at 212°
304-310		Attacked
316	Dry gas	0.0042-0.042 at 70°
	Moist gas	0.042-0.12 at 70°
	Gas	0.12-0.42 at 212°
	Sat. sol.	<0.0437 at 68°
321, 347		Attacked
410, 420		× at 70°
430		Same as 302
430F, 442		× at 70°

STEEL CORRODENT AND CONCENTRATION CORROSION RATE (IN./YR., °F.)

Citric Acid		
302	5% quiet	<0.0042 at 70°-150°
	10%-50%	<0.0042 at 70°
302	10%, 15%	0.0042-0.042 at b.
	25%, 50%	0.12-0.42 at b.
	Conc.	0.042-0.12 at b.
	5% at 45 psi.	0.12-0.42 at 284°
	Sat.	<0.004 at 70°
	25% sol. + 0.6% H ₂ SO ₄	<0.0044 at 68°
	25% sol. + 0.75% H ₂ SO ₄	<0.131 at 68°
	50% sol. + 0.6% H ₂ SO ₄	<0.0044 at 68°
304	15%, sat.	<0.004 at 70°
	15%	<0.040 at b.
308	Sat.	<0.004 at 70°
309		
310		
316	5% quiet	<0.0042 at 70°-150°
	10%-50%	<0.0042 at 70°-b.
	Conc.	0.0042-0.042 at b.
	5% at 45 psi.	0.0042-0.042 at 284°
	Sat.	<0.004 at 70°
321, 347	Sat.	<0.004 at 70°
403	Sat.†	<0.005 at 70°
410	5% quiet	<0.0042 at 70°-150°
	Sat.†	<0.005 at 70°
420	6%	0.005 at 64°
430	5% quiet	<0.0042 at 70°-150°
	10%	<0.0042 at 70°
	15%	<0.0042 at b.
	33%	0.007 at 64°
430F	1-50%	<0.0046 at 68°-b.
442	5%	<0.004 at 70°

Copper Sulphate

302	50% (sat.)	<0.0044 at 212°
	+ 10% H ₂ SO ₄	<0.0044 at 68°
	Sol.+3% H ₂ SO ₄	<0.0046 at 68°
302	5% ag.	<0.0042 at 70°
	Sat.	<0.0042 at b.
304	Sat.	<0.004 at 70°, b.
308		
309		
310	Sat.	<0.004 at 70°
316		Same as 302
321, 347	Sat.	<0.004 at 70°
403, 410	5% ag.	<0.0042 at 70°
	Sat.	<0.005 at 70°
	Sat. (neutral)	* at high temp.
430	5% ag.	<0.0042 at 70°
	Sat.	<0.004 at 70°
	Sat. (neutral)	* at high temp.
430F	Sol.+3% H ₂ SO ₄	<0.0046 at 68°
442	Sat.	<0.004 at 70°

STEEL CORRODENT AND CONCENTRATION

CORROSION RATE (IN./YR., °F.)

Chromic Acid

302	5%, c. p.	<0.0042 at 70°
	10%, 50%, c. p.	0.004-0.04 at 70°, 0.04-0.12 at b.
	50% commercial + SO ₃	<0.0042 at 70°, >0.12 at b.
304	5%	<0.010 at 70°
308-310		Attacked at 70°
316	5%, c. p.	<0.0042 at 70°
	10%, 50%, c. p.	0.004-0.04 at 70°, 0.004-0.04 at b.
	50% commercial + SO ₃	<0.0042 at 70°, 0.042-0.12 at b.
321-403, 410		Attacked at 70°
430	10%	<0.0046 at 70°, 0.046 at b.
	50%	>0.46 at 70°, >0.46 at b.
430F	10%	<0.0046 at 70°, <0.0046 at b.
	50%	<0.46 at 70°, >0.456 at b.
431		Same as 430
442		Attacked at 70°

STEEL CORRODENT AND CONCENTRATION CORROSION RATE (IN./YR., °F.)

Ethyl Acetate		
302	Conc.	<0.003 at 70°
304-347	Conc.	<0.003 at 70°
403, 410	Conc.	<0.005 at 70°
Ethyl Alcohol		
302	10-100% alcohol	<0.0042 at 70°, b.
		<0.0044 at 68°
304-347	Conc.	<0.004 at 70°
316		<0.0042 at 70°, b.
403, 410		<0.005 at 70°
430-431		<0.0042 at 70°, b.
Ethylene Glycol		
302	Conc.	<0.003 at 70°
304-347	Conc.	<0.003 at 70°
403, 410	Conc.	<0.005 at 70°
Fatty Acids		
302		<0.004 at 70°
304-347		<0.004 at 70°
430F		<0.0046

Ferric Chloride		
302	1%†, ‡	0.0042-0.042 at 70°
	1%†, ‡	0.12-0.42 at b.
	Sat.	Attacked at 70°
304	5%	× at 70°
	Sat.	Attacked at 70°
308		
309	Sat.	Attacked at 70°
310		
316	1%†, ‡	<0.0042 at 70°
	1%†, ‡	0.042-0.12 at b.
	10%†, ‡	<0.004 at 70°
	10%†, ‡	<0.004 at 70°
316	10%†, ‡	<0.004 at 70°
321, 347	Sat.	Attacked at 70°
403	5% (sat.)	× at 70°
420		
430	1%†, ‡	0.0042-0.042 at 70°
	1%†, ‡	0.12-0.42 at 70°
	5% (sat.)	× at 70°
430F, 442	5% (sat.)	× at 70°

Ferric Sulphate

302	1%, 5% quiet, ag.	<0.0042 at 70°
	10%	<0.0042 at b.
	Sat.	<0.004 at 70°
304	5%† and sat.	<0.004 at 70°
308-310	Sat.	<0.004 at 70°
316	1%, 5% quiet, ag.	<0.0042 at 70°
	10%	<0.0042 at b.
	Sat.	<0.004 at 70°

STEEL CORRODENT AND CONCENTRATION CORROSION RATE (IN./YR., °F.)

Ferric Sulphate (Cont.)		
321, 347	Sat.	<0.004 at 70°
410, 420	5%	<0.004 at 70°
430, 430F	1%, 5% quiet, ag.	<0.0042 at 70°
431, 442	Sat.	<0.004 at 70°

Ferrous Chloride		
316	Sat.	<0.004 at 70°

Ferrous Sulphate		
302	10%†	<0.0042 at 70°-b.
	Sat.	<0.004 at 70°
304	Dilute	<0.004 at 70°
	Sat.	<0.004 at 70°
308-310	Sat.	<0.004 at 70°
316	Dilute	<0.004 at 70°
	10%	<0.0042 at 70°-b.
	Sat.	<0.004 at 70°
321, 347	Sat.	<0.004 at 70°
403, 410	Dilute	<0.004 at 70°
	Sat.	<0.005 at 70°
420	Dilute	<0.004 at 70°
430, 430F	Dilute†	<0.004 at 70°
442	Sat.	<0.004 at 70°

Formaldehyde		
302	40%†	<0.004 at 70°
304-310	40%†	<0.004 at 70°
316	40%	<0.004 at 70°
321, 347	40%†	<0.004 at 70°
403, 410	40%†	<0.005 at 70°
430, 430F	40%†	<0.004 at 70°
431, 442	40%†	<0.004 at 70°

Formic Acid		
304-310	5%	<0.004 at 70°
316	5%	<0.0042 at 70°
	10%	<0.0042 at 70° and b.
	50%	<0.0042 at 70° and b.
	90%	<0.0042 at b.
	100%	<0.0042 at 70°, 0.004-0.040 at b.
321, 347	5%	<0.004 at 70°
403, 410		Attacked at 70° and b.
430	5%	0.004-0.040 at 70°
	10% }	{ 0.004-0.040 at 70°, >0.42 at b.
	50% }	{
430F	10%	<0.0046 at 70° and b.
	50%	<0.0046 at 70° and b.
	80%	<0.0046 at 70° and b.
	100%	<0.0046 at 70° and b.

Furfural		
304, 316		<0.004 at 70°

Gelatin		
302, 316, 410, 430		Little or none

Corrosion Resistance of the Stainless Steels in Wrought and Cast Form

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Glue		
302	Dry	<0.0042 at 70°
	Acid sol.†	0.0042-0.042 at 70° and 140°
304	Acid sol.†	<0.004 at 70° and 150°
308-310	Sol.	<0.004 at 70°†
316	Dry	<0.0042 at 70°
	Acid sol.	<0.0042 at 70° and 140°
321, 347	Sol.	<0.004 at 70°†
403, 410	Dry	<0.0042 at 70°
	Sol.	<0.005 at 70°†
430-431	Dry	<0.0042 at 70°
	Sol.	<0.0046 at 68°

Glycerine		
302-431		<0.004 at 70°

Hydrochloric Acid		
302-442	All conc.	>0.42 at 70°
CA-40	1%, 5%	>0.5 at 95°
CB-30		
CC-35		
CE-30		
	1%	0.080 at 70°
	1%	0.1-0.5 at 95°
	5%	>0.5 at 95°
CF-7	0.25%	* at 70°
CF-10	0.25%	* at 70°
	1%	* at 70°
	1%, 5%	0.1-0.2 at 95°
	1%, 5%	>0.5 at b.
CF-16	0.25%, 1%	* at 70°
CF-7M	0.25%	* at 70°
	1%	>0.001 at 70°
CG-10M	0.25%, 1%	* at 70°
CH-20	0.25%	* at 70°
	1%	0.060 at 70°
	1%	0.067 at 95°
	1%	>0.5 at b.
CH-10M	0.25%, 1%	* at 70°, b.
	1%	0.003 at b.
CH-20M	0.25%	* at 70°, b.
	1%	<0.001 at 70°
	1%	0.004 at b.
CK-25	1%	0.13-0.14 at 95°
	1%	>0.5 at b.
	5%	0.11-0.16 at 95°
CM-25	1%	0.15 at 95°
	5%	0.13 at 95°

Hydrofluoric Acid		
302-442		Attacked

Hydrogen Peroxide		
302	H ₂ SO ₄ absent	<0.0042 at 70°
	H ₂ SO ₄ absent	0.0042-0.042 at b.
304-310	Acid free	<0.004 at 70°
316		<0.004 at 70° and b.
321-403	Acid free	<0.004 at 70°
410		
430	H ₂ SO ₄ absent	<0.0042 at 70°
	H ₂ SO ₄ absent	0.0042-0.042 at b.
430 F	Acid free	<0.004 at 70°
431		
442		

Iodine		
302-310		>0.42 at 70°
316		0.12-0.42 at 70°
321-442		>0.42 at 70°

Lactic Acid		
302	1%	<0.004 at 70°, <0.004 at b.
	5%	<0.004 at 70°, 0.004-0.04 at 150°, 0.004-0.04 at b.
	10%	<0.004 at 70°, 0.04-0.12 at 150°, 0.12-0.42 at b.
	Conc.	<0.004 at 70°, 0.042-0.12 at b.

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Lactic Acid (Cont.)		
304-310	5%	<0.004 at 70°
316	1%	<0.004 at 70°, <0.004 at b.
	5%	<0.004 at 70°, <0.004 at 150°, <0.004 at b.
	10%	<0.004 at 70°, 0.004-0.04 at 150°, 0.004-0.04 at b.
	Conc.	<0.004 at 70°, 0.004-0.04 at b.
321, 347		<0.004 at 70°
403, 410		<0.1 at 70°
430	1%	<0.004 at 70°, 0.004-0.04 at b.
	5%	0.004-0.04 at 70°, 0.004-0.04 at b.
	10%	0.004-0.04 at 70°, >0.4 at b.
430 F	10%	<0.005 at 70°, <0.005 at b.
	Conc.	<0.005 at 70°, <0.005 at b.
431	10%	<0.05 at 70°, <0.05 at b.
	Conc.	<0.05 at 70°, <0.5 at b.
442	10%	<0.04 at 70°

Magnesium Chloride		
302	1%, 5%, quiet	<0.0042 at 70°†
	1%, 5%, quiet	0.042-0.12 at hot†
	10-30%	<0.0044 at 68°†
	Sat.	<0.004 at 70°†
304	5%	<0.007 at 70°†
	Sat.	<0.004 at 70°†
308-310	Sat.	<0.004 at 70°†
316	1%, 5%, quiet	<0.0042 at 70°
	1%, 5%, quiet	0.0042-0.042 at hot†
	Sat.	<0.004 at 70°
321, 347	Sat.	<0.004 at 70°†
403, 410	5%	<0.040 at 70°†
	Sat.	<0.100 at 70°†
430, 442	1%, 5%, quiet	<0.0042 at 70°†
	Sat.	<0.004 at 70°†

Methanol		
302		<0.0042 at 70°
		0.042-0.12 at 150°†
304-310		<0.004 at 70°
316		<0.0042 at 70°
		0.0042-0.042 at 150°
321, 347		<0.004 at 70°
403, 410		<0.004 at 70°
420		<0.0042 at 70°
430		0.042-0.12 at 150°
430 F, 431		<0.004 at 70°
442		<0.004 at 70°

Mixed Acids (H₂SO₄ + HNO₃)		
	H ₂ SO ₄	HNO ₃
302, 316	15% +	5%
	30% +	5%
	30% +	5%
	58% +	40%
	58% +	40%
	58% +	40%
	70% +	10%
	70% +	10%
	1% +	99%
	10% +	90%
		<0.044 at 230°
		<0.0044 at 203°
		<0.044 at 230°
		<0.0044 at 140°
		<0.044 at 203°
		>0.131 at 230°
		<0.0044 at 140°
		<0.044 at 203°
		<0.044 at b.
		<0.044 at b.

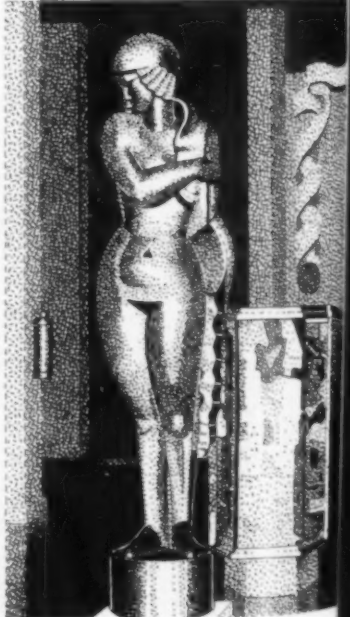
Abbreviations:

*Recommended
 x Not recommended
 †Pitting may occur when allowed to dry, by condensation, or at the air-liquid level
 ‡Attack may occur if free acid is present
 ag. Agitated or aerated
 b. Boiling liquid
 Conc. Concentrations or concentrated solution
 C.p. Chemically pure
 Sat. Saturated solution
 Sol. Solution

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Nitric Acid		
302	5-50% 65% Conc. Fuming conc.	<0.0042 at 70°, 0.0042 at b. <0.0042 at 70°, 0.004-0.04 at b. <0.0042 at 70°, 0.04-0.12 at b. <0.004 at 70°, <0.004 at 110°, 0.12-0.42 at b.
304	5% 20% 65% Conc. Conc.	<0.004 at 70°, 0.013 at 110° <0.004 at 70° <0.030 at b. <0.004 at 70° <0.004 at 70°
308, 309 310	5% Conc.	0.0084 at 110° <0.004 at 70°
316	5-50% 65% Conc. Fuming conc.	<0.0042 at 70°, <0.0042 at b. <0.0042 at 70°, 0.004-0.04 at b. <0.004 at 70°, 0.04-0.12 at b. <0.004 at 70°, <0.004 at 110°, 0.12-0.42 at b.
321, 347 403, 410	Conc. 5% and 20% 65% Conc.	<0.004 at 70° <0.020 at 70° × at b. <0.005 at 70°
420	5% 20% 65% Conc.	<0.020 at 70° <0.020 at 70° >0.42 at b. <0.0042 at 70°, >0.42 at b.
430	5% 20%-50% 65% Conc. Fuming conc.	<0.0042 at 70°, 0.042-0.12 at b. <0.0042 at 70°, 0.004-0.04 at b. <0.0042 at 70°, 0.042-0.12 at b. <0.0042 at 70°, 0.12-0.42 at b. <0.004 at 70°, <0.004 at 110°, 0.12-0.42 at b.
430 F, 431	10% 25% 50%-conc.	<0.0046 at 70° and b. <0.0046 at 70°, <0.046 at b. <0.0046 at 70°, <0.46 at b.
442	Conc.	<0.004 at 70°
CA-14	20% 65%	* at 70° * at 70°, 0.13-0.16 at b.
CA-40	20% 65%	* at 70° * at 70°, 0.45 at b.
CB-30	0.5-20% 65%	* at 70° and b. * at 70°, 0.20 at b.
CC-35	0.5-20% 65%	* at 70° and b. * at 70°, 0.02-0.04 at b.
CD-10 M	0.5-65%	* at 70° and b.
CE-30	0.5-20% 65%	* at 70° and b. * at 70°, 0.020 at b.
CF-7	0.5-20% 65%	* at 70° and b. * at 70°, 0.008 at b.
CF-10	0.5-20% 65%	* at 70° and b. * at 70°, 0.02-0.03 at b.
CF-16	0.5-65%	* at 70° and b.
CF-20	0.5-20% 65%	* at 70° and b. * at 70°, 0.05-0.4 at b.
CF-7C	0.5-65%	* at 70° and b.
CF-7M	0.5-20% 65%	* at 70° and b. * at 70°, 0.018 at b.
CF-16M CG-7 CG-7C CG-10M CG-16M CH-10 CH-20	0.5-65% 0.5-65% 0.5-65% 0.5-65% 0.5-65% 0.5-20% 65%	* at 70° and b. * at 70° and b. * at 70°, 0.016 at b. * at 70° and b. * at 70°, 0.018 at b. * at 70° and b. * at 70°, 0.010 at b.
CH-10M CH-10M CH-20M	0.5-20% 65% 0.5-20% 65%	* at 70° and b. * at 70° and b. * at 70° and b.
CR-25	0.5-20% 65%	<0.001 at 70°, 0.004-0.007 at 176°, 0.01-0.03 at b.
CM-25	65%	0.042 at b
Oleic Acid		
302		<0.0042 at 70-400°†
304-310		<0.004 at 70°
316		<0.0042 at 70-400°
321, 347, 410, 420		<0.004 at 70°
430		0.004-0.04 at 70° and 300°†
430 F, 431		<0.004 at 70°

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Oxalic Acid		
302	5% 10% 50% Sat.	<0.0042 at 70° and b. <0.0042 at 70°, 0.12-0.42 at b. 0.12-0.42 at b. <0.0044 at 70°, <0.0044 at 104°, >0.44 at b.
304	10% Sat.†	<0.004 at 70°, × at b. <0.004 at 70°
308-310	Sat.†	<0.004 at 70°
316	5% 10% 50% Sat.	<0.004 at 70° and b. <0.004 at 70°, 0.04-0.12 at b. 0.04-0.12 at b. <0.004 at 70°, <0.004 at 104°, 0.146 at b.
321, 347 403, 410	Sat.† 5% 10% 10%	<0.004 at 70° 0.004-0.04 at hot or cold <0.046 at 68° >0.46 at b.
430	5% 10% 10% Sat.†	<0.0042 at 70°, b. 0.0042-0.042 at 70° >0.42 at b. <0.004 at 70°
430 F	10% 10-50% Sat.†	<0.0046 at 70° <0.46 at b. <0.004 at 70°
442	Sat.†	<0.004 at 70°
Phenol		
302	C. p. + 10% water C. p. Crude Crude	<0.0042 at b. <0.0042 at 70°-b. <0.0042 at 212° <0.0042 at b.
304-310 316	Commercial† C. p. + 10% water C. p. Crude Crude	<0.004 at 70° <0.0042 at b. <0.0042 at 70°-b. <0.0042 at 212° <0.0042 at b.
321, 347 410, 420 430	Commercial† C. p. + 10% water C. p. Commercial†	<0.004 at 70° <0.040 <0.0042 at b. <0.0042 at 70° <0.004 at 70°
430 F, 431 442	Sol. Commercial†	<0.0046 at 68°-b. <0.004 at 70°
Phosphoric Acid		
302	1%, 5% 10%, quiet	<0.0042 at 70°, <0.0042 at b. 0.004-0.04 at 70°
302	10%, ag.	0.04-0.12 at 70°
304	1% 10%, ag.	<0.0042 at 70° <0.12 at 70°
308-310 316	<0.0042 at 70° 1%, 10% 25%, 50% 85% 85%, ag.	<0.0042 at 70° <0.0042 at 70°, <0.0042 at b. <0.0042 at 70°, 0.004-0.04 at b. <0.0042 at 70°, 0.04-0.12 at b. 0.042 at 70°
321, 347 403 410 420 430	<0.0042 at 70° 1%, 5% 10% 1% 1%, 5%	<0.0042 at 70° <0.0042 at 70° 0.12-0.42 at 70° <0.0042 at 70°, <0.046 at b. 0.04-0.12 at 70°, 0.12-0.42 at b.
430 F	1-45% Conc.	<0.0046 at 70° and b. <0.0046 at 70°, <0.46 at b.
431	1-10% 45% Conc.	<0.0046 at 70° and b. <0.046 at 70°, <0.46 at b. <0.046 at 70°, >0.46 at b.
442	5%	<0.0042 at 70°
CB-30	10-85%	* at 70° and b.
CC-35	50% 85%	* at 70° * at 70°, <0.001 at 95°, >1.0 at b.
CD-10 M	10%, 50% 85%	* at 70° and b. * at 70°
CE-30	10%, 50% 85%	* at 70° * at 70° >1.0 at b.

Corrosion Resistance of the Stainless Steels in Wrought and Cast Form

STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)	STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)	STEEL	CORRODENT AND CONCENTRATION	CORROSION RATE (IN./YR., °F.)
Phosphoric Acid (Cont.)			Sodium Hydroxide			Sodium Sulphate		
CF-7	10% 50% 85%	* at 70° and b. * at 70° 0.001 at 70°	302, 316	20% sol. 30% sol. Molten	<0.0042 at b. 0.0042-0.042 at b. 0.0042-0.042 at 600°	302	5% - sat. Sat.	<0.0042 at 70° <0.0042 at b.
CF-10	10%, 50% 85%	* at 70° and b. * at 70°, <0.001 at 95°, >1.0 at b.	304-310 321, 347 403, 410 420-446		<0.004 at 70° <0.004 at 70° <0.005 at 70° <0.004 at 70°	304-310 316 321, 347 403, 410 430 442	Sat. Sat. Sat. 5% 5% Conc. Sat.	<0.004 at 70° Same as 302 <0.004 at 70° No attack <0.0042 at 70° 0.042-0.12 at 70° <0.004 at 70°
CF-16	10%, 50% 85%	* at 70° and b. * at 70°	CA-14 CB-30 CC-35	0.5% 0.5-70% 0.5% 50%, 70%	* at 70° * at 70° * at 70° and b. * at 70°	Sodium Sulphide		
CF-7C	10-85%	* at 70°	CD-10M CE-30	70% 0.5%, 50%	* at 70° and b. * at 70° and b.	302	5% 50% Sat.	Little or none at 70° <0.001 at 194° 0.004-0.04 at 70°
CF-7M	10%, 50% 85%	* at 70° and b. <0.001 at 70°	CF-7	70%	* at 70°	304-310 316	Sat. 5% 50% Sat.	<0.004 at 70° Little or none at 70° <0.001 at 194° <0.0042 at 70°
CF-16M	10%, 50% 85%	* at 70° and b. * at 70°	CF-10 CF-16	0.5%-70% 0.5%	* at 70° and b. * at 70° and b.	321, 347 403, 410	Sat. 5% Sat.†	<0.004 at 70° Slight at 70° <0.005 at 70°
CG-7	10%-85%	* at 70°	CF-20	0.5%	* at 70° and b.	430	5% 50% Sat.	Slight at 70° >0.46 at b. <0.004 at 70°
CG-10	10%, 50%	* at 70° and b.	CF-7C	0.5%, 50%	* at 70°	430 F, 431 442	Sat. Sat.	<0.004 at 70° <0.004 at 70°
CG-7C	85%	* at 70°	CF-7M	0.5%-70%	* at 70° and b.	Sodium Sulphite		
CG-10M	10-85%	* at 70° and b.	CF-16M	0.5%, 50%	* at 70° and b.	302	5% 10% 25%, 50% Sat.	<0.0042 at 70° <0.0042 at 150° <0.0042 at b. <0.004 at 70°
CG-16M	85%	* at 70°	CG-7	0.5%, 50%	* at 70° and b.	304	5% 10% Sat.	<0.004 at 70° <0.004 at 150° <0.004 at 70°
CH-20	10% 50% 85%	* at 70° and b. * at 70° * at 70°, nil at 95°, >1.0 at b.	CG-10 CG-7C CG-10M CG-16M	0.5-70% 0.5-70% 0.5%, 50% 0.5%, 50%	* at 70° and b. * at 70° and b. * at 70° and b. * at 70° and b.	308-310 316 321, 347 403, 410 430 442	Sat. Sat. Sat.† 5% 25% Sat. Sat.	<0.004 at 70° Same as 302 <0.004 at 70° <0.005 at 70° 0.042-0.12 at 70° <0.0042 at b. <0.004 at 70° <0.004 at 70°
CH-10M	10%, 50%	* at 70° and b.	CH-20	0.5-70%	* at 70° and b.	Sodium Nitrate		
CH-20M	85%	* at 70°	CH-10M	0.5-70%	* at 70° and b.	302	Sat. Fused	<0.004 at 70° 0.0042-0.042
CK-25	85%	* at 70°, nil at 95°, >1.0 at b.	CH-20M	0.5-70%	* at 70° and b.	304-310 316	Sat. Sat.	<0.004 at 70° <0.004 at 70°
Sodium Bisulphate			CK-25	0.5-70%	* at 70° and b.	321, 347 403, 410 430 430 F, 431 442	Sat. sol. Sat. sol. Sat. sol. Fused Sol. Sat. sol.	<0.004 at 70° <0.005 at 70° <0.004 at 70° 0.042-0.12 <0.0046 at 68° <0.004 at 70°
302	10% Sat.	<0.0044 at 68-212° Attacked	Sodium Hypochlorite			Sodium Phosphate (Tribasic)		
304	Sol. Sat.	<0.004 at 70° Attacked	302	5% Sat.	0.0042-0.042 at 70° Attacked, except for short periods	302-347 430, 442		<0.004 at 70° <0.004 at 70°
308-310	Sat.	Attacked	304-310	Sat.	Same as 302			
316	2g. + 1g. H ₂ SO ₄ per liter	<0.0044 at 68° and 212°	316 321, 347 403, 410 430	5% (sat.) Sat. Sat. 5%	<0.004 at 70° Same as 302 Attacked 0.042-0.12 at 70°			
321-410	Sol. Sat.	<0.004 at 70° Attacked	CB-30 CC-35 CE-30 CF-7 CF-10 CF-16 CF-7M CF-16M	Short immersions, not attacked at 70° 5% free Cl ₂ 5%, 20% Cl ₂ 5%, 20% Cl ₂ 5%, 20% Cl ₂ 5% free Cl ₂ 5%, 20% Cl ₂	* at 70° * at 70° * at 70° and b. * at 70° * at 70° and b. * at 70° and b. * at 70° and b. * at 70°			
Sodium Carbonate			CG-7 CG-7C CG-10M CG-16M CH-20 CH-20M	5% free Cl ₂ 5%, 20% Cl ₂ 5% free Cl ₂ 5% free Cl ₂ 20% free Cl ₂ 5% free Cl ₂	* at 70° * at 70° * at 70° and b. * at 70° and b. * at 70° and b. * at 70°			
302, 316	5-50% Sat. Molten	<0.0042 at 70°-b. <0.004 at 70° >0.42 at 1650°	CK-25	5% free Cl ₂	* at 70°			
304	5% Sat.	<0.004 at 70-150° <0.004 at 70°						
308-310	Sat.	<0.004 at 70°						
321, 347	Sat.	<0.004 at 70°						
403, 410	10% - sat.	<0.0046 at 68-212°						
420	5%	<0.004 at 70-150°						
430	5%	<0.0042 at 70°-b.						
430 F	10% - sat.	<0.0046 at 68-212°						
442	5%	<0.004 at 70-150°						
446	Sat.	<0.004 at 70°						
446	10% - sat.	<0.0046 at 68-212°						
Sodium Chloride								
302	5%† 20%, aerated† Sat.†	<0.0042 at 70° and 150° <0.0042 at 70° <0.0042 at 70°, 0.004-0.04 at b.						
304-310	Sea water†	<0.004 at 70°						
316	5% sol. 20%, aerated Sat.	<0.0042 at 70° and 150° <0.0042 at 70° <0.0042 at 70° and b.						
321, 347	Sea water†	<0.004 at 70°						
403	Sea water†	Attacked						
410, 430	5% sol.†	0.004-0.04 at 70° and 150°						
420	Sea water†	Attacked, × at 70°						

CORRODENT AND
CONCENTRATIONCORROSION RATE
(In./Yr., °F.)

Sodium Thiosulphate (Hypo)

302	25%†	<0.0042 at 70° and b.
	Hypo (acid fix- ing bath)	<0.0042 at 70°
	Sat.†	<0.004 at 70°
304-310	Sat.	<0.004 at 70°
316		Same as 302
321, 347	Sat.	<0.004 at 70°
403, 410	Sat.	<0.005 at 70°

Stearic Acid

302		<0.0044 at 176°
	Conc.	Little or none at 200°
304-310		<0.004
316		Same as 302
321, 347		<0.004
403, 410		<0.004
	Conc.	Little or none at 200°
	Commercial	>0.1 at 420°
430-431		<0.004

Sulphur Dioxide

302	Moist gas†	0.0042-0.042 at 70°
	Dry gas	<0.0042 at 575°
304	Moist gas	<0.040 at 70°
	Dry gas	<0.004 at 575°
308-310		<0.004 at 70°†
316	Moist gas	<0.0042 at 70°
	Dry gas	<0.0042 at 575°
321, 347		<0.004 at 70°†
430	Moist gas	0.042-0.12 at 70°
	Dry gas	<0.0042 at 575°
442		<0.004 at 70°†

Sulphuric Acid

302	5%	0.04-0.12 at 70°, >0.42 at b.
	10%	0.04-0.12 at 70°, >0.42 at b.
	50%	0.12-0.42 at 70°, >0.42 at b.
	Conc.	<0.004 at 70°, >0.42 at 300°, 0.12-0.42 at b.
	Fuming	0.04-0.12 at 70°
304	3%	0.049 at 70°
	3-40%	>0.10 at 70°, >0.10 at 180°
	5%	>0.10 at 110°
	Conc.	<0.004 at 70°
308, 309	Conc.	<0.004 at 70°
310	5%	0.078 at 110°
	Conc.	<0.004 at 70°
316	5%	0.004-0.04 at 70°, 0.04-0.12 at b.
	10%	0.004-0.04 at 70°, 0.12-0.42 at b.
	50%	0.04-0.12 at 70°, 0.12-0.42 at b.
	Conc.	<0.004 at 70°, >0.42 at 300°, 0.12-0.42 at b.
	Fuming	0.004-0.04 at 70°
321, 347	Conc.	<0.004 at 70°
403, 410	Conc.	<0.005 at 70°
430	5%	0.04-0.12 at 70°, >0.42 at b.
	10%	0.04-0.12 at 70°, >0.42 at b.
	50%	>0.42 at b.
	Conc.	<0.004 at 70°, >0.42 at 300°, 0.12-0.42 at b.
442	Conc.	<0.004 at 70°
CA-40	2-10%	>1.0 at 95°
CB-30	2%	0.88 at 95°
	10%	>1.0 at 95°
CC-35	0.5%	* at 70°
	2%	0.29 at 95°
	10%	>1.0 at 95°
CD-10M	0.5%	* at 70° and b.
	2.5%	* at 70° and b.
	60%, 95%	* at 70°
CE-30	0.5%	* at 70°
	2%	<0.003 at 95°, >1.0 at b.
	2.5%	0.004 at 70°
	10%	0.03 at 70°, 0.03 at 95°, >1.0 at b.
CF-7	0.5%	* at 70°
	2.5%	0.2 at 70°
	10%	0.7 at 70°

CORRODENT AND
CONCENTRATIONCORROSION RATE
(In./Yr., °F.)

Sulphuric Acid (Cont.)

CF-10	2%	0.001-0.2 at 95°, >1.0 at b.
	10%	0.7 at 95°, >1.0 at b.
CF-16	0.5-10%	* at 70°
CF-20	2%	0.001-0.002 at 95°, 0.004-0.5 at 131°
	10%	0.02-1.0 at 95°, >0.5 at 131°
CF-7C	0.5%, 2.5%, 95%	* at 70°
CF-7M	0.5%	* at 70°
	2.5%	0.002 at 70° and b.
	10%	0.003 at 70°
CF-10M	0.5%-10%	* at 70°
CF-16M	0.5%	* at 70° and b.
	2.5-95%	* at 70°
CG-7	0.5%, 2.5%, 95%	* at 70°
CG-10		
CG-7C		
CG-10M	0.5%-95%	* at 70°
CG-16M	0.5%	* at 70° and b.
	2.5-95%	* at 70°
CH-10	0.5%, 2.5%, 95%	* at 70°
CH-20	0.5%	* at 70°
	2%	<0.001 at 70°, 0.002-0.01 at 131°, 0.7-3.0 at b.
	10%	0.005 at 70°, 0.004-0.02 at 95°, >1.0 at b.
CH-10M	0.5-95%	<0.004 at 70°
CH-20M	0.5%	* at 70° and b.
	2.5%	<0.001 at 70°, 0.08 at b.
	10%	0.001 at 70°, 0.4 at b.
	95%	* at 70°
CK-25	0.5%	* at 70°
	2%	* at 70°, 0.16 at 95°, 1.1 at b.
	10%	0.12 at 95°, >1.0 at b.
	95%	* at 70°

Sulphurous Acid (see also Sulphur Dioxide)

302	Sat.†	0.042-0.12 at 70°
	Sat.† at 150 psi.	0.042-0.12 at 375°
	Spray†	0.12-0.42 at 70°
304		× at 250°
316	Sat.†	0.0042-0.042 at 70°
	Sat.† at 60 psi.	0.0042-0.042 at 250°
	Sat.† at 70-125 psi.	0.042-0.12 at 310°
	Sat.† at 150 psi.	0.042-0.12 at 375°
	Spray†	0.12-0.42 at 70°
410, 420		× at 250°
430		Same as 302
430F		× at 250°

Tannic Acid

302	Sol.	<0.0042 at 70°
	Sol.	0.0042-0.042 at 150°
	10%	<0.0046 at 68°
	10%	<0.131 at b.
	50%	<0.0046 at 68°-b.
304	Sol.	<0.004 at 70-150°
308-310	Sol.	<0.004 at 70°
316	Sol.	<0.0042 at 70-150°
	10%	Same as 302
	50%	Same as 302
321, 347	Sol.	<0.004 at 70°
410	Sol.	0.0042-0.042 at 70°
	Sol.	0.042-0.12 at 150°
430	Sol.	<0.0042 at 70-150°
	Sol.	<0.046 at b.

Trichlorethylene

302	Pure	<0.0044 at 68-189°
304-347		<0.004 at 70°†
410, 430		Little or none at 70°

Abbreviations:

* Recommended
 × Not recommended
 † Pitting may occur when allowed to dry, by
 condensation, or at the air-liquid level
 ‡ Attack may occur if free acid is present
 ag. Agitated or aerated
 b. Boiling liquid
 Conc. Concentrations or concentrated solution
 C.p. Chemically pure
 Sat. Saturated solution
 Sol. Solution

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Wrought Magnesium— Alloys, Properties, Fabrication and Uses

OF ALL THE METALS, magnesium has had the most meteoric rise during the war. Ingot production capacity was expanded some 100 fold. By the beginning of 1944, before all new plants were finished, production of new metal had reached the annual rate of well above current demand. Since then a large stock pile has been accumulated, and metal released freely to all civilian uses.

Prewar uses of magnesium in America, other than for a strengthening element in aluminum alloys, were largely confined to castings. Even at present, the largest consumption is in foundries. However the war has stimulated work on wrought alloys, and several strong alloys are now available from four producers in the United States in a wide variety of forms—plate, sheet, bars, wire, shapes, tubes, extrusions. Plants for converting ingot into such forms, financed both by private industry and by the Government, increased by several thousand per cent from 1939 until 1944. Whereas before the war there were only a dozen fabricators, today there are hundreds who are thoroughly familiar with the engineering advantages of these light alloys and the methods of fabrication.

Magnesium alloys have been extensively used in aircraft for instrument panels, pilot seats, door panels, wing tips, fairings. Ordnance has used magnesium alloys for mortar bases, gun carriages, artillery wheels and rocket launchers.

Consideration has been given to the use of wrought magnesium alloys for furniture, ladders,

textile equipment, portable tools, truck bodies, office equipment, baby carriages, wheelbarrows and a host of other applications wherein weight-saving has some importance.

In any case the decision to use magnesium (as is true for other metals and alloys) should be based on some functional value to be achieved. If the strength of magnesium alloys, in combination with their light weight, enables one to design a structure of lighter weight with ample strength, or a structure of equivalent weight with greater

strength and stability, and substantial benefits are to be derived therefrom, economic or otherwise, then magnesium alloys and only magnesium alloys should be used.

The following data on the recently developed magnesium alloys, now readily available in wrought form, have been assembled to enable the intelligent user, engineer and designer to decide such pertinent questions.

Alloying Elements

To obtain desirable engineering properties, suitable workability and optimum corrosion resistance, pure magnesium is alloyed with other elements, of which the principal ones are:

Aluminum, added to wrought alloys within the range of 2.5 to 9% to increase the tensile strength and hardness.

Manganese is added sometimes alone, other times in combination with aluminum or other elements, also to increase tensile strength and improve corrosion resistance.

Zinc is added to the wrought aluminum-bearing alloys to improve the corrosion resistance. Zinc, in amounts between 0.5 and 1.5%, enables the alloy to tolerate more iron as an impurity without loss in corrosion resistance.

Calcium is added as a grain refiner, usually in amounts between 0.1 and 0.3%. (Ductility is lowered by coarse grain size.) It is particularly efficacious in the binary manganese-magnesium alloys and the 4% aluminum-magnesium alloys.

Cerium has been added to the manganese-magnesium alloys for increasing high temperature stability. Favored by the Germans, these alloys are still in the developmental stage in America.

Zirconium is mentioned in German patents which claim that zirconium and zinc produce a workable alloy possessing both high tensile and yield strengths. These alloys have not yet been marketed in this country.

The corrosion resistance of the aluminum-magnesium alloys is drastically influenced by iron, nickel and copper and present specifications establish maximums of 0.005% each for iron and nickel and 0.05% for copper. However, iron and nickel are seldom higher than 0.002% each, nor copper more than 0.01% in commercial alloys. Zinc, as stated above, acts as a palliative, otherwise it would be necessary to reduce the iron well below the above maximum to obtain the same corrosion resistance.

Commercial Wrought Alloys

There are at present five principal wrought magnesium alloys available generally as sheet, strip, plate, extrusions, tubing and forgings. Their properties, particular characteristics and chemical compositions are given below. The designations are those adopted by Revere Copper & Brass, Inc., and Dow Chemical Co. The designations in parentheses are those of American Magnesium Corp.

Alloy M (AM3S) contains 1.5% manganese and approximately 0.10% calcium. It has the best deep drawing characteristics, is lowest in cost, has good corrosion resistance, can be readily welded by gas or heliarc, and has the lowest tensile strength. Tensile strength will range from 29,000 to 37,000 psi., yield strength from 15,000 to 26,000 psi., elongation from 18 to 4%. It is available in all wrought forms. It will take light forming operations at room temperature, involving bend radii of $4\frac{1}{2}t$ (t is thickness of part being bent) for the annealed alloy and $8t$ for the hard condition. At a temperature of 400° F. the bend radius for hard sheet is increased to $7t$ and $3t$ for soft, whereas at 600° F., the recommended working temperature, radii for both tempers are reduced to $1t$. At this temperature it is also possible to make a deep draw of 73%, which is considerably greater than is possible with any other commercial alloy under recommended operating conditions. This alloy possesses excellent corrosion resistance to rural, industrial and marine atmospheres, being superior to mild steel. It is not susceptible to stress-corrosion cracking. It has the best creep strength of any of the cur-

rent magnesium alloys and generally better high temperature stability.

Alloy FS-1 (AMC52S) contains 3% aluminum, 1% zinc and about 0.15% calcium. This alloy is one of the most versatile of all; as far as sheet applications are concerned, it is "the old work horse". It is next in cost to alloy M, possesses the best formability at any temperature, has drawing characteristics almost as good as alloy M, has excellent resistance to general corrosion and has the greatest resistance to stress corrosion of any of the high strength alloys. It can be readily fusion welded. Its tensile strength ranges from 37,000 psi. for the annealed condition to 46,000 psi. for the hard; yield strength from 23,000 to 35,000 psi.; elongation from 25 to 10%. At room temperature alloy FS-1 can be formed easier and to smaller radii than the other alloys; for example, hard temper needs a radius of $7t$, soft temper $3\frac{1}{2}t$; soft temper at 400° F. and hard temper at 450° require no more than a radius of $1t$. At 300° F. (below the softening temperature for annealing the cold rolled sheet) this alloy has an elongation of 40%, almost twice its room temperature value; therefore difficult parts can be formed from hard metal and still retain the higher strengths of the hard temper. Best working is done in the range of 450 to 500° F. This alloy is available generally as sheet, strip, extrusions and forgings.

Alloy JS-1 (AMC54S), newest addition to the magnesium alloy family, contains 5% aluminum, 1% zinc and may have up to 0.30% calcium. It was developed primarily to replace the old 6.5% aluminum alloy for sheet production, and is covered by an amendment to Army-Navy aeronautical specification AN-M-28.

The higher aluminum alloy, which JS-1 replaces for sheet and strip production, was an extremely difficult alloy to fabricate, and under certain conditions it was quite susceptible to stress-corrosion cracking. The new alloy, being a compromise between Alloys FS-1 and J-1 (the next one to be mentioned), possesses intermediate properties. It has higher tensile strengths and yield strengths than the 6.5% aluminum alloy, greater toughness, better formability, greater resistance to stress-corrosion cracking, equivalent general corrosion resistance and weldability, better fatigue strength and slightly lower creep strength. Tensile strength will range from 40,000 to 50,000 psi., tensile yield strength from 24,000 to 40,000 psi., elongation from 20 to 10%. This alloy should find its greatest application where high strength in combination with excellent weldability is desired. It is available only as sheets.

Alloy J-1 (AMC57S) contains 6% alumi-

num and 0.75% zinc. It has been fabricated by rolling, extrusion and forging but will not be rolled into sheet after present stocks are utilized. In the extruded and hot forged condition, this alloy has tensile strengths around 42,000 to 46,000 psi. It is used where such strength is required.

Alloy O-1 (AMC58S) contains 8.5% aluminum and 0.50% zinc. It has the highest strength of any of the magnesium alloys, but the poorest forming characteristics, so it is only used in those applications requiring the greatest strength and hardness. It is only fabricated as extrusions and forgings. It is the only magnesium alloy that reacts to heat treatment and it is commercially furnished either in the as-extruded, as-forged, or aged condition. Tensile strength, as worked, will be about 50,000 psi. with a yield strength of about 30,000. After aging 10 hr. at 375° F. following working, the tensile strength will increase slightly and the yield strength will approach 35,000 psi.

Fabrication Methods

The methods by which magnesium alloys may be fabricated and the manner in which they differ from other metal will be briefly discussed.

Fusion Welding — All of the alloys may be readily welded. Gas welding technique is very similar to that for aluminum, as well as design of joints and jiggling or tooling. Due to the corrosive character of the flux it must be thoroughly removed. Excellent joints can also be made by arc welding, using filler rod of the same composition and a tungsten electrode surrounded by an atmosphere of argon or helium. Joint efficiencies of 90 to 98% are not uncommon. Most welders consider magnesium alloys among the most weldable of alloys and definitely easier to weld than aluminum alloys. Higher strengths can be obtained in magnesium alloy joints than with aluminum alloys.

Spot Welding — All the magnesium alloys are spot welded in equipment suitable for aluminum. It is necessary to clean faying surfaces prior to welding. A chemical method said to be more desirable than scratch brushing was developed by Consolidated Vultee Aircraft Corp., and consists of immersion in 5 to 10% caustic soda at 150° F. for 5 min., rinsing in cold running water, immersing in 20% chromic acid at 150° F. for 2 min., rinsing in cold running water, and drying in air. This treatment passivates the surface so that but little change in surface resistance will occur in 24 hr.

Bonding — Any of the magnesium alloys can be joined or bonded to each other or to other

metals and materials with cements based on synthetic rubber or plastic, of which there are several on the market. Strengths up to 3000 psi., which are more than double the strength secured by riveting, can be obtained. Pressures and curing time are essentially the same for magnesium alloys as for other material. To secure maximum strength, the faying surfaces must be clean and free of chemicals, grease or rouge.

Soldering of magnesium alloys cannot yet be considered commercial.

Riveting technique and equipment is the same as used for aluminum alloys. The main difference is in the type of rivet used. Magnesium alloy rivets are not commercially available, so anodized aluminum alloy 56S rivets are used. There is no corrosive couple set up between the magnesium and the rivet.

Forming — Hand forming, press forming, rubber forming or roll forming utilize equipment and methods of the same type as are used for other metals. Due, however, to the greater formability of the magnesium alloys at slightly elevated temperature, it is recommended that dies and work be heated to between 450 and 600° F., depending upon the alloy. Radii of bends will, in turn, be determined by the alloy, its temper and the temperature of working, as already noted when describing the alloys.

Deep Drawing — The main feature in the deep drawing of magnesium alloys is that it is always done above room temperature. Temperatures will vary from 450 to 650° F., depending on the alloy. There is no advantage in using any temper but annealed, as after drawing the properties of the drawn part will be those of annealed material. Hydraulic presses with operating speeds of 6 to 8 ft. per min. and mechanical presses with speeds up to 60 ft. per min. have been used successfully. Die and punch design is somewhat special, and provisions should be made for preheating. For most work the punch should have a radius equal to 6 to 8 times the sheet thickness while the die should have a minimum radius of 8 times the sheet thickness. Dies may be heated by gas or electricity; work may be heated in place or in an adjacent oven. Tallow and graphite or a colloidal suspension of graphite in a volatile carrier may be used as a lubricant. It may be possible to heat stock for shallow draws in an oil bath, using one of the commercial oils with high flash point. While it might seem that a lot of extra steps are thus involved, it must be borne in mind that because of the greater workability of magnesium at the proper temperature, more can be accomplished in one operation than in several operations with other metals such as

aluminum or brass at room temperatures. This saves interstage operations, die costs and power. Those who have become familiar with the deep drawing of magnesium alloys would rather work them than other metals.

Machinability—The magnesium alloys possess the best machinability of any metals. They can be machined faster, with lower power consumption, lower tool costs and lower coolant cost than any other metal. Clearance and rake angles are more generous and tools should be kept very sharp at all times. It is possible to take heavy cuts at surface speeds of 700 ft. per min. without coolants; due to the low cutting pressure required and the relatively high thermal conductivity of the metal, the work remains cool. When taking very fine cuts at high surface speeds, it is desirable to use a non-water soluble oil. High clamping pressures tend to cause greater springing in magnesium than in most other metals under similar conditions. For this reason, care should be taken when clamping and chucking magnesium.

Spinning—All of the magnesium sheet alloys can be spun. Equipment and speed of operation are similar to other metals, but work should be done at an elevated temperature, depending on the alloy, which will range from 450 to 650° F.

Physical Properties

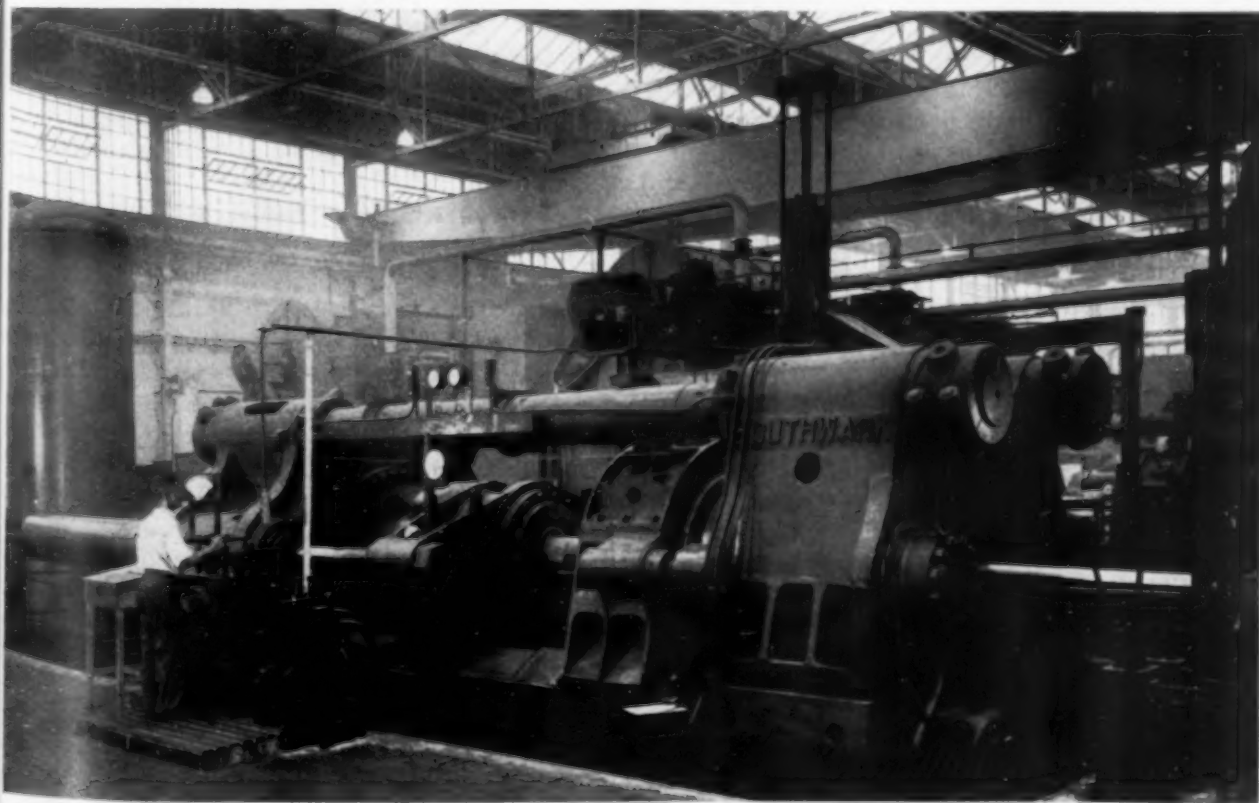
Other characteristics which must be evaluated to determine correct use for a given application are weight, corrosion resistance, design characteristics and combustibility.

Weight—The magnesium alloys are the lightest engineering metals used today. They have a specific gravity of 1.80. They weigh 0.064 lb. per cu.in., or 112 lb. per cu.ft., compared with birch at 44, maple at 49, water 63, aluminum 173 lb. per cu.ft., steel 493, brass 591, and lead 706.

Corrosion resistance of the magnesium alloys now made is far superior to those available before the war. Metallurgical improvements, impurity control and better ingot casting practices have resulted in alloys which have much better corrosion resistance to ordinary exposures than mild steel and some aluminum alloys. No one would consider using steel without providing some protective coating and accordingly it is good practice to protect magnesium alloys against corrosion by suitable paint systems or coatings.

Uncoated magnesium alloys possess excellent resistance to hydrofluoric acid, alkalis and pure chromic acid. They can be used in contact with oils, greases, kerosene, gasoline and many other hydrocarbons. For applications involving

4400-Ton Extrusion Press for Making Shapes and Tubing of Strong Magnesium Alloys. (Courtesy Revere Copper & Brass, Inc.)





contact with salt air or water, a good protective system consists of one or two primer coats of zinc chromate followed by a coat of aluminized lacquer.

Baked enamel finishes of the "Hiresite" type afford excellent protection. Plastic base lacquers and paints are also being used; others are being developed which show great promise. One-coat paints are receiving some consideration for applications not involving severe corrosion; for example, coatings of the vinylite type have been tried and show that magnesium alloys can be protected as readily as other metals.

Within the past year an anodic treatment developed by the Consolidated Vultee Aircraft Corp. has received considerable attention. The coating developed, mainly oxides and hydroxide, is very adherent, impervious and hard. It is about 100 times more resistant to abrasion than the standard Dow No. 7 treatment, and not quite so hard as the anodic film on aluminum alloys. Due to the dielectric strength of the film, galvanic corrosion in contact with dissimilar metals is reduced. It is also possible to dye the coating. It is customary to seal the anodic coating by dipping the anodized part into a dilute zinc chromate bath.

Some work has been done on nickel and chromium plates for magnesium alloys. These processes, however, are still in the development stage. Due to the high potential which exists between magnesium and chromium, and the porous characteristics of any plate, outdoor exposure of plated magnesium articles is not generally recommended.

Design Characteristics

While the magnesium alloys have the lowest modulus of elasticity in tension of any of the industrial metals, they also possess the lowest density, with mechanical properties substantially close to those of mild steel, as rolled, thus making it frequently possible to substitute them for the heavier metals either with a weight saving in combination with equivalent stiffness, strength in bending, or fatigue, or with no weight saving

in combination with better strength and greater stability by reason of greater section.

Because magnesium alloys can be joined so easily by fusion welding, and because of the greater efficiency of such joints compared with other light alloys, it is possible to design to higher stresses than with welded aluminum alloys.

When magnesium alloys are considered as substitutes for steel, wood, aluminum or other metals, design should be on a basis of equal elastic stiffness. Since elastic stiffness is a function of the moment of inertia of the section (I) and the modulus of elasticity of the material (E), it is possible, by making slight changes in dimensions, to produce substantially lighter sections of equal stiffness and greater strength in bending. For example, a magnesium alloy section of equal stiffness weighing 50 to 65% that of structural steel is possible. It is also possible to substitute magnesium for wood at a substantial weight saving, even though wood is lighter than magnesium.

All magnesium alloys, whether cast or wrought, have higher damping capacities than any of the aluminum alloys. This property is particularly important in reciprocating parts or machine parts receiving rapid stresses from adjacent equipment or parts. In such parts vibration would be smaller if magnesium alloys were used than in the case of aluminum and its alloys.

Magnesium alloys are very resilient and possess a high resistance to shock loads. Resilience of a material for a given applied stress is inversely proportional to its modulus of elasticity. Due to its low modulus, magnesium alloys (within their elastic range) possess greater resilience than aluminum or steels, and as a consequence can absorb more shock by energy loads without undergoing damage.

The statement is often made that magnesium alloys will burn and, consequently, they present a hazard to shops or fabricators. It is true that magnesium alloys in the finely divided condition will burn, but equally combustible and dangerous are powdered coal, aluminum and flour. One is more concerned about dirt than about fire when his winter's fuel arrives and the cellar is filled with coal dust, but since much publicity has been given to the incendiary characteristics of magnesium powder used for fire bombs, the conclusion is drawn by otherwise uninformed individuals that magnesium in any form will ignite readily. As a matter of fact, magnesium in fabricated forms or mill products is as resistant to ignition as any of the common metals and as long as proper precautions are taken to exhaust grinding or machining dust and chips, no fire hazard exists.

MORE THAN MATERIAL...

MACHINABILITY

The sealing plug for aircraft hydraulic mechanisms at the left is a good example of what we're talking about. A lot of machining goes into its fabrication on hand screw machines and drill presses—machining which costs considerably more than the steel from which it is made.

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Specific Effects of Alloys in Steel

Element	Solid Solubility		Influence Upon Ferrite	Influence Upon Austenite (Hardenability)	Influence Exerted Through Carbide		Principal Functions
	In Gamma Iron	In Alpha Iron			Carbide Forming Tendency	Action During Tempering	
Aluminum Al	1.1% (Increased by C)	30% ±	Hardens considerably by solid solution	Increases hardenability mildly, if dissolved in austenite	Less than Fe (Graphitizes)	.....	1. Deoxidizes efficiently. 2. Restricts grain growth (by forming dispersed oxides or nitrides) 3. Alloying element in nitriding steel
Chromium Cr	12.8% (20% with 0.5% C)	Unlimited	Hardens slightly; increases corrosion resistance	Increases hardenability moderately, similarly to manganese	Greater than Mn; Less than W	Mildly resists softening	1. Increases corrosion and oxidation resistance 2. Increases hardenability 3. Adds some strength at high temperatures 4. Resists abrasion and wear (with high carbon)
Cobalt Co	Unlimited	80% ±	Hardens considerably by solid solution	Decreases hardenability as dissolved	Similar to Fe	Sustains hardness by solid solution	1. Contributes to red hardness by hardening ferrite
Manganese Mn	Unlimited	15 to 18%	Hardens markedly; reduces plasticity somewhat	Increases hardenability moderately, similarly to chromium	Greater than Fe; Less than Cr	Very little, in usual percentages	1. Counteracts brittleness from the sulphur 2. Increases hardenability inexpensively 3. Forms better resistant steel (high Mn, high C)
Molybdenum Mo	3% ± (8% with 0.3% C)	32%, (Less with lowered temperature)	Provides age-hardening system in high Mo-Fe alloys	Increases hardenability strongly (Mo > Cr)	Strong; Greater than Cr	Opposes softening, by secondary hardening	1. Raises coarsening temperature of austenite 2. Deepens hardening 3. Raises hot and creep strength, red hardness 4. Enhances corrosion resistance in stainless 5. Forms abrasion-resisting particles
Nickel Ni	Unlimited	25% ± (Irrespective of carbon content)	Strengthens and toughens by solid solution	Increases hardenability mildly, but tends to retain austenite with higher carbon	Less than Fe (Graphitizes)	Very little in small percentages	1. Strengthens unquenched or annealed steels 2. Toughens pearlitic-ferritic steels (especially at low temperature) 3. Renders high chromium-iron alloys austenitic
Phosphorus P	0.5%	2.5% (Irrespective of carbon content)	Hardens strongly by solid solution	Increases hardenability, similarly to manganese	Nil	.....	1. Strengthens low carbon steel 2. Increases resistance to corrosion 3. Improves machinability in free-cutting steels
Silicon Si	2% ± (9% with 0.35% C)	18.5%, (Not much changed by carbon)	Hardens with loss in plasticity (Mn < Si < P)	Increases hardenability more than nickel (Ni < Si < Mn)	Negative (Graphitizes)	Sustains hardness by solid solution	1. Used as general purpose deoxidizer 2. Alloy for electrical and magnetic sheet 3. Improves oxidation resistance 4. Increases hardenability of steels carrying non-graphitizing elements 5. Strengthens low alloy steels
Titanium Ti	0.75% (1% ± with 0.20% C)	6% ±, (Less with lowered temperature)	Provides age-hardening system in high Ti-Fe alloys	Probably increases hardenability very strongly, as dissolved. Its carbide effects reduce hardenability	Greatest known (2% Ti renders 0.50% carbon steel unhardenable)	Persistent carbides probably unaffected. Some secondary hardening	1. Fixes carbon in inert particles (a) Reduces martensitic hardness and hardenability in medium chromium steels (b) Prevents formation of austenite in high chromium steels (c) Prevents localized depletion of chromium in stainless during long heating
Tungsten W	6% (11% with 0.25% C)	32%, (Less with lowered temperature)	Provides age-hardening system in high W-Fe alloys	Increases hardenability strongly in small amounts	Strong	Opposes softening by secondary hardening	1. Forms hard, abrasion resistant particles in toolsteels 2. Promotes red hardness and hot strength
Vanadium V	1.5% ± (4% with 0.30% C)	Unlimited	Hardens moderately by solid solution	Increases hardenability very strongly, as dissolved	Very strong (V < Ti or Cr)	Maximum for secondary hardening	1. Elevates coarsening temperature of austenite (promotes fine grain) 2. Increases hardenability (when dissolved) 3. Resists tempering and causes marked secondary hardening

Revised, 1942. Adapted from "The Functions of the Alloying Elements in Steel" by Edgar C. Bain; published by

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October, 1945; Page 725

1. promotes coarse grain
(promotes fine grain)
2. hardenability (when dissolved)
3. Reheats hardening and causes marked secondary hardening

secondary hardening
by Edgar C. Bain; published by

(V < Ti or Cr)

very strongly, as dissolved

very by solid solution

The Functions of the Alloying Elements in Steel

0.20% O

Revised, 1942. Adapted from

TOOL STEEL DATA

Revised data for Oil and Air Hardening Die Steels including types, analyses, uses, hardening characteristics and temperature ranges

OCTOBER, 1945

OIL AND AIR HARDENING DIE STEEL CHARACTERISTICS					
TYPE	GRADE	ANALYSIS	USES For Cold Work Dies, and Tools Requiring:	HARDENING CHARACTERISTICS	
				HARDENING TEMPERATURES	QUENCH RC
High Carbon High Chrome	SUPERDIE	C 2.10 Si .90 Cr 10.50 W .80	<ul style="list-style-type: none"> • Close Tolerances • Greatest Production • Best Wearing Ability 	Range: 1700° F. to 1750° F. Small or Intricate Sections 1700° F. Large Sections 1750° F.	Oil 64-66 Air 58-62
High Carbon High Chrome	ATMODIE	C 1.50 Cr 12.00 Mo .80 V .90	<ul style="list-style-type: none"> • Minimum Warpage • Long Life 	Range: 1800° F. to 1850° F. Small or Intricate Sections 1800° F. Large Sections 1850° F.	Air 62-64
Non-Deforming Deep Hardening	OILDIE	C .90 Mn .60 Cr 1.50 W .50	<ul style="list-style-type: none"> • Accurate Dimensions • Good Cutting Qualities 	Range: 1500° F. to 1550° F.	Oil 62-64
Non-Deforming Standard Type	EXL-DIE	C .90 Mn 1.15 Cr .50 W .50 V .10	<ul style="list-style-type: none"> • Little Dimensional Change • Ease in Hardening 	Range: 1480° F. to 1525° F.	Oil 62-64
MARTEMPERING: The oil hardening die steels can be quenched in hot salts maintained at 400° F. After which they can be cooled in air to room temperature. This will reduce stresses ordinarily set up in this temperature range.					
TEMPERING: For maximum hardness temper from 350° F. to 400° F. The High Carbon, High Chrome steels can be tempered up to 900° F. where increased toughness is desired, and double tempering is recommended.					
GRINDING: For grinding use a clean free cutting wheel. For final tool sharpening, a cutter grinder with fine grit such as No. 320, with removal up to .001" will give a fine finish and substantially lengthen the life of the tool.					

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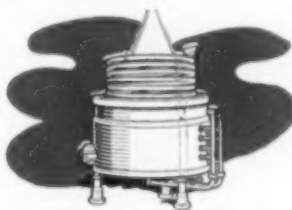
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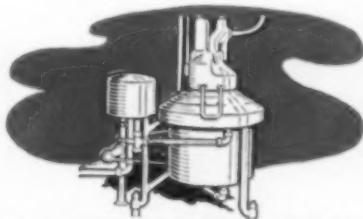
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Aluminum is resistant to attack by a wide variety of corrosive media harmful to other metals. With outdoor furniture this means resistance to sun, rain, snow; in industry it includes smoke, fumes, oils, many chemicals.



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Industrial Uses of Minor Metals*

LITHIUM is used mainly as a powerful deoxidizer or hardening and grain refining addition to alloys — for example, lithium-copper and lithium-silver master alloys are used for deoxidizing copper and silver. Lithium may also be produced as a calcium-lithium alloy for treating cast iron, plain carbon steel, stainless steel and copper alloys. Lead, hardened with small amounts of lithium, has been used as a substitute for babbitt metal. Lithium also hardens aluminum-zinc alloys and magnesium. Added to molten cast iron, lithium improves the fluidity and tensile strength, removes gaseous inclusions and disperses the graphite more uniformly. Lithium-treated mild steel and 18-8 are said to have higher elastic properties than untreated materials. Probably the most important use of lithium as a deoxidizer is in the production of high conductivity, oxygen-free cop-

per. The lithium also removes sulphur, nitrogen and hydrogen during the deoxidation of molten alloys. If heating gases are passed over lithium before entering a work chamber the moisture and other oxygen-containing gases appear to be fixed so they have little or no reactivity with the hot steel they come in contact with.

Beryllium has its greatest use in the 2% beryllium-copper alloy which may be heat treated and aged to 350 to 420 Vickers hardness. This alloy has found extensive application for springs and non-sparking tools. Alloys of beryllium with the light metals are of little present value, while the alloys with nickel and iron are age-hardenable but have not yet been widely used. A platinum alloy with 0.06% beryllium is as hard as a 20% iridium-platinum. Copper, nickel and iron may be surface hardened by cementation with powdered beryllium. Pure beryllium has found a limited use for windows of X-ray tubes.

Gallium has no industrial use

owing to its scarcity and price. It decreases the melting point of Wood's metal. It has been suggested for fused quartz thermometers for use to 1800°. Electrodeposited, it might be used as a protection against tarnish. Plated deposits can be diffused in copper and silver to give a hard corrosion resisting surface layer. Gallium-silver and gallium-copper alloys resemble closely the corresponding indium alloys.

Indium is used chiefly as a plating metal for protecting lead surfaces from oil corrosion and bearings. Small amounts of indium are used to increase the strength of gold and platinum dental alloys. A Wood's metal with 18% indium has a melting point of 118° F. and has been used in dentistry and plastic surgery.

Thallium has no industrial use in metallic form although a thallium-lead alloy is said to be highly corrosion resistant. Thallium reduces the melting point of fusible metals but is not nearly so effective in this respect as indium.


Cerium and Rare Earth Metals are used mainly as an iron alloy in cigarette lighter flints, and

(Continued on page 742)

*Abstracted from "Minor Metals", by A. R. Powell, *Metal Industry*, June 15, p. 374 and June 29, 1945, p. 406.

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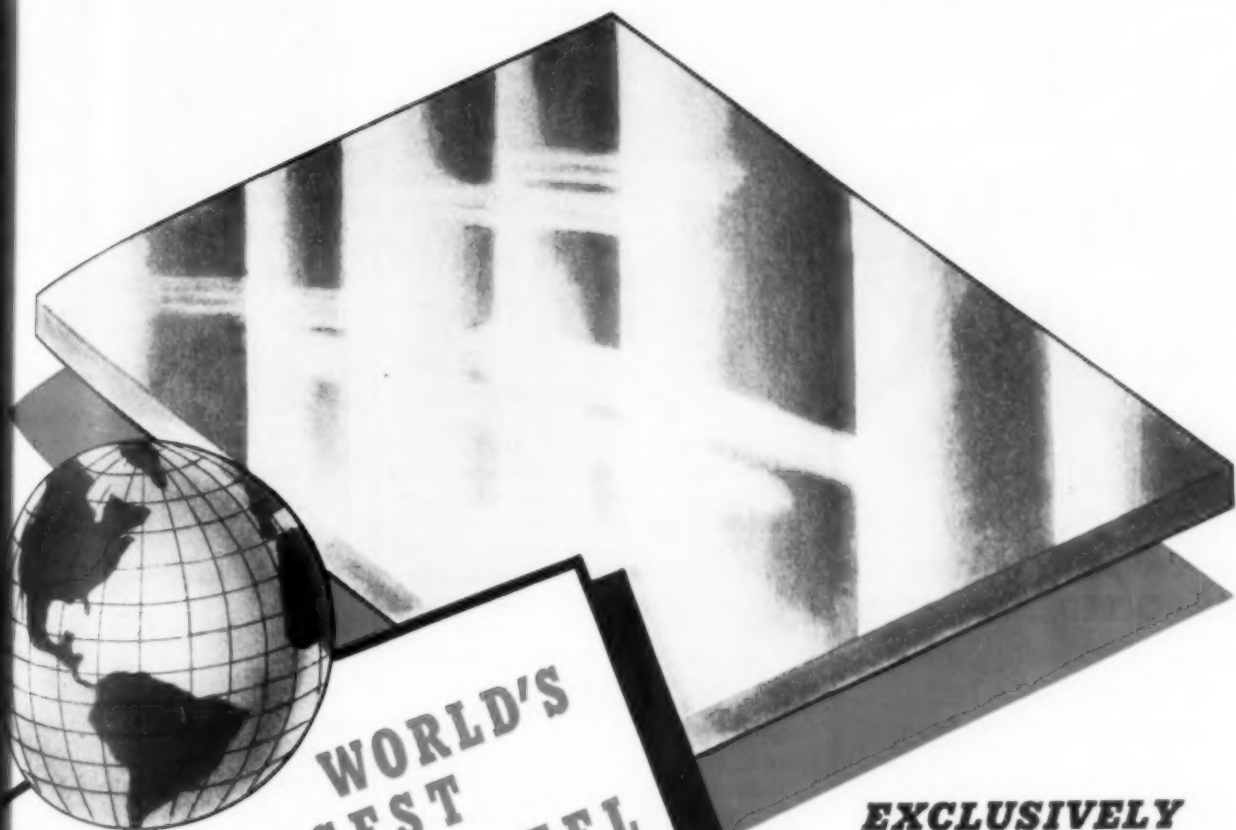
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Minor Metals

(Continued from page 740)

refining the grain of magnesium and aluminum alloys. Cerium oxide has found a considerable market as an opacifier for enamels in place of tin oxide. The use of ceria as a substitute for rouge as a more effective glass polishing medium is increasing.

Thorium finds extensive use in the electronic industry in X-ray targets, photo-electric cells and glow tube cathodes. Thoria mantles for gas burners—once very important—are now in minor demand. Thoriated tungsten wire has been used for many years in radio valves and electric lamp filaments. The 1 to 2% thorium restrains grain growth and provides the source of thermionic emission in the filaments of radio valves.

Titanium is a very important scavenger and grain refiner for steels and aluminum alloys. It is an important substitute for vanadium in the strengthening and toughening of the low alloy steels. It is used to fix the carbon as in soluble carbides, thus preventing intergranular corrosion in stainless steel, and to make ferrous alloys and nickel-cobalt alloys of the Konel type age-hardenable. Titanium-copper alloys are age-hardenable but are not yet used commercially. Pure titanium is a useful "getter" in high vacuum technique. Titanium oxide is used in pigment, enamel and in the coating of welding rods.

Zirconium has found little industrial use although it is a good "getter" in vacuum tubes and has been used tentatively in various radio valves. Zirconia is a good opacifier for enamels but is not the equal of ceria.

Columbium is used to stabilize stainless steel in the same way as titanium. It is also an important element in alloys to resist high temperature. No doubt it will be possible to use it for the same purposes as tantalum is now used.

Tantalum is the most corrosion resistant of the non-precious metals and therefore is being used successfully for covering surfaces exposed to highly corrosive influences. Tantalum diaphragms and valves are used in handling chlorine and hypochlorite solutions as well as for rayon spinnerets. It can be hardened to about 500 Brinell by carburizing or nitriding. Tantalum is superior to molybdenum as a grid material; tantalum plates are also useful in electronic tubes. ☉

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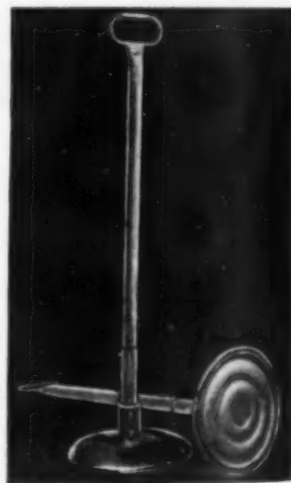
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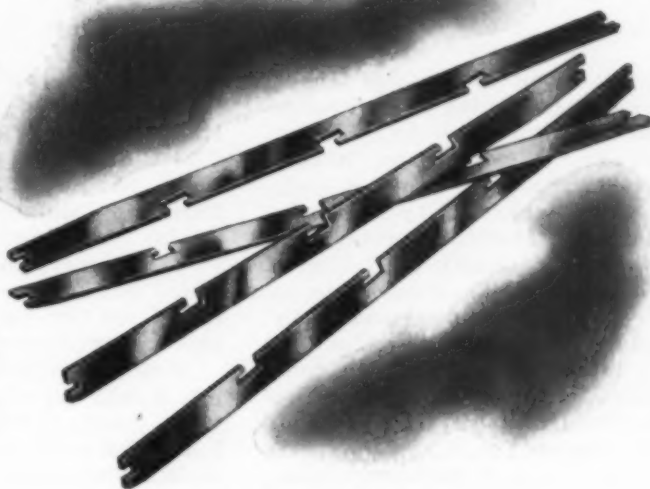
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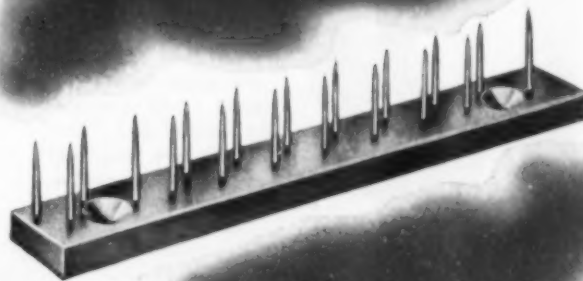
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High Strength Plate for the Navy*

THE analysis of the high tensile steel used by the Navy for ship construction had to be changed early in the war because it contained vanadium. Simultaneously the steel's weldability had to be improved. Therefore, statistical methods and quality control were used to control the composition to give a happy medium between the required strength and weldability. The latest developments in computing devices were applied to solve the multiple regression problems involved.

The prewar manganese-vanadium steel was changed to a manganese-titanium analysis. In 1944 when vanadium again became available, a new, lower cost high tensile steel was adopted with superior weldability. It is of the manganese-titanium-vanadium type.

Average analysis for six steel

*Abstracted from "The Application of Statistical Methods to the Development and Quality Control of High Tensile Steel", by Charles M. Mottley, Lieut., U.S.N.R., *Journal of the American Society of Naval Engineers*, Vol. 57, No. 1, February, 1945, p. 21.

producers during the manganese-titanium period was: 0.16% C, 1.30% Mn, 0.020% P, 0.026% S, 0.24% Si, 0.10% Cu, 0.10% Cr, 0.09% Ni, 0.04% Mo, 0.016% Ti. There were differences among the plants; one made a steel with a very high carbon content; two added nickel; two added chromium, and two used sufficient titanium to act as an alloy.

Average properties were 76,800 psi. tensile strength, 48,000 psi. yield point, 25.4% elongation in 2 in. The total range of inter-heat variation for both yield point and tensile strength was excessively high (25,000 psi.), due partly to low values at the start of the program before quality control became effective. The chief difficulty was in meeting the required yield point of 48,000 psi. min.

The specification had no weldability test, but Tee-bend tests were made in the hope of developing a satisfactory inspection test. The average angle at maximum load was 59.7°.

Chemical variations accounted for about 75% of the total variation

in the tensile strength. The carbon and manganese were most responsible; titanium, phosphorus and silicon had a lesser share, while variations in the other elements had negligible effect. Titanium was very important in the two plants whose steels contained an average of over 0.02%.

Variations in chemical elements accounted for about 50% of the total variation in yield point. Mill variations such as in the finishing temperature also have more effect on yield than on the tensile strength. Carbon and manganese had the greatest effect; titanium and phosphorus came next and the effect of the other elements was negligible.

Chemistry accounted for under 40% of the variation in elongation with titanium the most important element.

Variations in chemical composition were responsible for only 35% of the Tee-bend results with chromium most deleterious. Copper probably had a beneficial effect kept at 0.10%. The correlation between weldability and physical properties was even smaller. Clearly, this test involves important factors other than composition and physical properties.

(Continued on page 758)



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Metal Mold Castings

METAL MOLD CASTINGS are of the following types:

1. Permanent mold castings (including shell castings)
2. Semi-permanent mold castings
3. Castings made with external pressure (die castings)
 - (a) Die castings from basin machines
 - (b) Cold chamber pressure castings
 - (c) Pressure molded castings
4. Centrifugal castings

All metal mold castings have higher strength, better surface appearance, and closer tolerances than sand castings of the same metal—but they entail higher tool cost. Owing to their closer tolerances and good surface, metal mold castings usually avoid costly machining operations necessary with sand castings, except when *very* close tolerances are required. They frequently cost less than those forgings that require considerable machining, or drawn parts that necessitate more than one anneal in a series of draws, or even screw machine parts where much of the material is lost in chips.

Metal mold castings should be considered for every part where production is high or even moderately high (in one instance, zinc die castings with a yearly production of 150 have cost less than machined gray iron castings), and also where the mechanical requirements are not beyond the possibilities of the metals going into this family of castings.

The final selection of the metal mold process, in competition with sand casting or any other method of manufacture, especially under present economic conditions, will depend on the best balanced combination of:

1. Suitability of the material under consid-

eration and physical characteristics imparted to it by the process.

2. Competitive and advertising advantages through the use of the process.

3. Cost of tools and of each piece in a finished state, inclusive of all machining.

4. Total saving in cost of all finished pieces during the period allowed for the liquidation of tools.

5. Saving of machine-hours and man-hours and of scarce materials.

The length of time allowed for liquidation of tools—that is, for cancellation of the tool cost out of the savings effected in the manufacture of the finished part—varies with the job. If the order is not likely to be repeated, the period should be the life of the order. If it is a standard part, the period should depend on the prospective life of the design and on the engineering and advertising advantages derived from the use of the process.

Even after the economic and mechanical advantages of one or another form of metal mold process have been fully established, the designer should make sure that the design is definitely settled and not subject to early change owing to shifting sales sentiment or to service troubles. Ordinarily, the heavy investment in mold cost and the difficulty and delay usually involved in getting a new set of extensively machined alloy steel dies are likely to militate against an otherwise highly desirable change.

The design should be laid out for the selected form of metal mold, but if there is any uncertainty about the stability of the design it is advisable to handle production during the introductory period with sand castings or in some other less restricting form.

Permanent Mold Castings

In the permanent mold casting method, fluid metal is poured by hand into metal molds, and around metal cores, without external pressure. The molds are usually held together by C-clamps, although in some cases they are closed and opened by a screw or toggle.

Metals suitable for this type of casting are lead, zinc, aluminum and magnesium alloys, certain bronzes, and cast iron.

For making iron castings of this type, turntables on which a number of metal mold units are mounted are frequently employed, and the individual operations — such as coating the mold, placing the cores, closing the mold, pouring, opening the mold, and ejection of the casting — are performed as each mold passes certain stations.

Zinc-base permanent mold castings are usually slush castings. Metal molds are employed. After the molds have been filled with molten metal and as soon as the outer skin of the casting has solidified, the mold is up-ended and the still-liquid metal on the inside is allowed to run out, thus leaving a hollow thin-walled shell. The thickness of the wall can be controlled by the temperature of the molten metal poured into the

mold, the mold temperature and the interval of time between pouring in and out. The wall thickness, of course, is always irregular. In addition to zinc alloys, some lead alloys and aluminum alloys are suitable for such castings. They are often used for lighting fixtures, spouts, and similar decorative household ware.

The permanent mold provides castings having these advantages — first, a dense fine-grained structure, substantially free from shrink holes or blowholes; second, relatively low tool charges and third, better surface and closer tolerances than provided by sand castings.

On the other hand, the permanent mold process has two principal limitations, the inability to maintain as close tolerances and as thin sections as with die casting, or plaster-of-paris casting methods, and secondly, the yellow brasses which are high in zinc, are difficult to use because zinc oxide fouls the molds or dies.

The Die Casting Has Been Made, the Die Opened, and the Workman on the Far Side Is About to Lift the Casting From Its Mold. (Photo Courtesy Aluminum Co. of America)



Semi-Permanent Mold Castings

This method is the same as that for permanent mold castings except sand cores are used at some points instead of metal cores. The tool cost is lower than for permanent mold castings with metal cores. The same metals are suitable for casting.

The semi-permanent mold process is particularly applicable where cored openings are so irregular in shape or have such undercuts that metal cores would be too costly or too difficult to handle.

The disadvantage of the method lies in the fact that the structure of the metal around the sand cores is like that of a sand casting, and the advantages of permanent mold casting as to tolerances, density and appearance, exist only in the sections cast against the metal mold.

Castings With External Pressure

In these types, highly fluid metal is forced under considerable outside pressure into metal molds, which may be artificially cooled to speed production by hastening solidification of the casting and its removal from the mold.

Machines — Basin machine die castings are produced in machines which consist basically of a basin holding a considerable quantity of molten metal (enough for several hours' production and continually replenished), a metallic mold or die, and a metal-transferring device submerged in the basin which automatically withdraws a certain amount of molten metal from the basin and forces it under pressure into the die.

Two forms of die casting machines of this type are in general use. Lead, tin, and zinc alloys containing aluminum are handled in the so-called piston machine. Aluminum alloys, pure zinc, or zinc alloys free from aluminum require a different type of casting machine since these materials rapidly attack the iron in the piston and cylinder and destroy the required close fits between them.

Pressures back of the metal in the piston machine range from a few hundred to 5000 psi. The best practice for zinc-aluminum alloys is to use a minimum of about 1000 psi.

The goose-neck machine was developed primarily for aluminum alloys and is limited in pressure back of the metal to a maximum of about 700 psi. (350 to 550 psi. on the average). It is sometimes used for zinc-aluminum alloys, especially for large castings, but, owing to the lower pressure back of the metal, the structure is likely to be less dense than in castings made in the piston machine. It is seldom used for

magnesium alloys and is gradually being replaced by cold chamber machines, even for aluminum.

Cold chamber pressure castings (and controlled quality, pressure-molded castings) are produced in machines which are fundamentally different from either the piston or goose-neck die casting machines in that the molten metal reservoir is separated from the casting machine, and just enough metal for one shot is ladled into a small chamber, or pouring well, from which it is forced into the die under high pressure. Pressures back of the metal range from a few thousand to 10,000 psi. — at times even more. The machine is applicable to aluminum alloys, magnesium alloys, zinc alloys (although the commercial aluminum-bearing zinc alloys are usually handled in standard piston machines which can supply enough pressure for all purposes at higher production speed), and even alloys with high melting points like brasses and bronzes, since the pouring well, cylinder, and piston are exposed to the high temperature for only a short time.

Applications — Commercial zinc alloys have good strength and ductility and great resistance to shock (except at freezing temperature), but low creep strength. Zinc becomes increasingly brittle as operating temperatures fall to freezing and below, although initial properties are fully restored when temperature rises again. (Brass, aluminum and magnesium are little affected by freezing temperature.) Zinc alloys can be cast in thinner sections and with sharper outlines and closer tolerances than other commercial die casting alloys; they require less costly dies and less die maintenance; the production rate is higher on account of the low melting point of the alloy; and they can be plated easily with protective, as well as decorative coatings. Although zinc costs more on the volume basis than aluminum or magnesium, if zinc is suitable for the service to which the castings are subjected and if in dimensioning of sections full advantage is taken of its excellent casting properties, zinc castings may be cheaper than castings of any other metal.

In past years zinc alloy die castings were subjected to considerable criticism because of structural instability, especially in humid atmosphere, wherein they would after some time be likely to crack, swell, and even disintegrate. Metallurgical research has definitely proven that the trouble resulted from the presence of certain impurities in the zinc, and the lack of appreciation on the part of their manufacturers of the effect of certain alloying constituents. Zinc die castings, produced under adequate metallurgical control and to correct composition are reliable and safe, as demonstrated by their service record

for more than ten years. There is, however, usually a very small change in dimensions after the castings have been taken out of the die (which may for certain alloys be hastened through a short artificial aging, and in any case for practical purposes is completed after at least five weeks' air aging or after artificial aging). This change takes place because of phase adjustment in the alloy when cooling to room temperature. It is of the order of only a little more than half a mil and has no relation whatever to the former chemical instability.

Zinc alloys have good corrosion resistance against ordinary atmosphere, as well as in marine exposure, although not so good against industrial atmosphere.

Quenching of zinc die castings from the die—which is often done to castings of thin sections to prevent warping—increases the dimensional changes and should never be used when maxi-

erties and operating temperatures. However, their high melting point entails the difficulty of obtaining die steels of the same life and suitability as for casting zinc, aluminum or magnesium. Cost of brass die castings is considerably higher than the lighter metals—out of proportion to the difference in metal cost. They find application where neither zinc, aluminum or magnesium would do for reason of strength, corrosion resistance or temperature conditions, and where die casting eliminates so much machining that for the required production the high die cost will be absorbed. For low and moderate production quantities, plaster-of-paris castings will often be found to be more economical.

The range of physical properties for the various commercially used compositions of this general type of metal mold castings is as shown in Table I. Typical values obtained from separately cast test bars are listed.

Table I—Typical Properties of Die Cast Test Bars

TYPE	TENSILE STRENGTH	YIELD STRENGTH AT 0.2% OFFSET	ELONGATION	CHARPY IMPACT	BRINELL HARDNESS
Zinc* alloy	40,000 to 45,000 psi.	.....	3 to 5%	20† ft.-lb.	75 to 85
Aluminum alloy	30,000 to 40,000	14,000 to 24,000 psi.	2 to 6	2 to 10	60 to 80
Magnesium alloy	30,000 to 33,000	21,000	1 to 3	1 to 2	60 to 65
Brass‡	45,000 to 60,000	25,000 to 30,000	10 to 15	15	120 to 130

*As cast; some decrease in tensile and yield strength after prolonged indoor aging, but elongation increases slightly.

†Decreases markedly at sub-zero temperatures.

‡Special brass alloys will have tensile strengths up to

90,000 psi., with 60,000 psi. yield strength, and about 8% elongation.

imum dimensional stability is required, and where castings cannot be artificially or naturally aged for sufficiently long periods before machining.

Aluminum die casting alloys cover a wide range of physical, mechanical, and corrosion properties to suit a broad variety of applications.

Their light weight makes them suitable for jobs where zinc would be too heavy or unable to stand up under operating temperatures, and where magnesium would be unsuitable on account of severely corrosive conditions. Their chemical properties recommend them particularly for use where they come in contact with food and fruit acids.

Magnesium alloys, weighing only two-thirds of aluminum and one-fourth of zinc, are used in aircraft, portable devices, rotating and reciprocating apparatus, and other similar equipment. Magnesium die casting alloys have quite acceptable corrosion resistance against ordinary atmospheric attack, but are badly attacked by tropical humid climate and sea water.

Brass alloys offer the highest physical prop-

The figures in Table I must not be taken to indicate the strength of the casting, only of the metal when cast into certain standardized test bars under standard conditions.

Not all compositions of the zinc, aluminum, magnesium, or copper group which can be sand cast can also be cast in metal molds. This restriction results from hot shortness (weakness at solidifying temperature) or shrinkage being too great to enable them to withstand the unyielding force which certain parts of the metal mold may oppose to the contraction of the casting as it cools. Most castings have some detail of configuration, such as bosses, prongs or parallel ribs, which give rise to this circumstance.

All metal mold, external pressure castings share certain properties, although to a varying degree. They all have close tolerances, sharp outlines and contours, fine, smooth surfaces, and high speed of production with low labor cost. They all have a hard skin with a softer core owing to rapid chilling of the surface of the casting against the metal mold; consequently

excessive machining will disproportionately reduce the strength of the section and is apt to cause warping on account of the release of internal stresses held in check by the skin as long as it is unbroken. Machining will also reduce leakage resistance against internal pressure.

When exposed to high temperature, aluminum and magnesium alloy castings (more so with goose-neck die castings than with cold chamber pressure castings, or pressure molded castings) are likely to blister on the surface because of the expansion of air and gases trapped during solidification inside the casting by the rapidly hardening skin.

Owing to the rapid chilling and the resulting fine grain size of the structure, these castings all have greater strength in a solid section than the same composition cast by any other means, although it is difficult (again, more so with die castings than with cold chamber pressure castings, or pressure molded castings) especially in heavier sections, to obtain solid sections without some porosity, impairing strength.

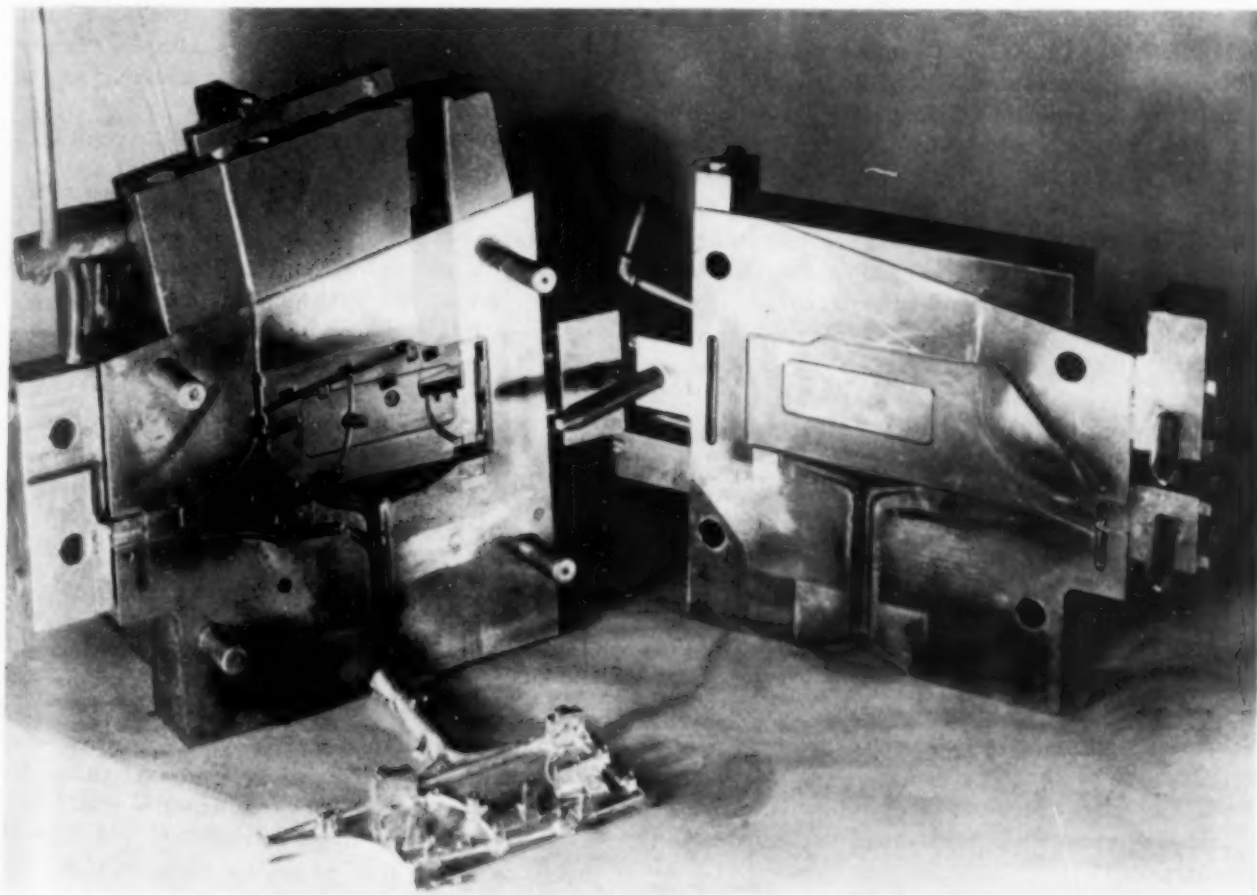
Aside from these characteristics common to all methods of external pressure metal mold castings, there are certain fundamental differ-

ences between them, particularly between the product of the goose-neck machine and that of the cold chamber machine.

In the former, the goose-neck, which dips the molten metal out of the metal container and transfers it to the die, is constantly immersed in the molten metal. It is made of cast iron to withstand the pressure back of the metal at the high metal temperature. The metal container is also usually of iron. At the temperature of molten aluminum, the aluminum strongly attacks the iron in the goose-neck and container, with the result that the aluminum gradually absorbs a large amount of iron. This absorbed iron affects the castability of the aluminum and the strength, ductility, machinability, shock resistance, and other properties of the castings.

In the cold chamber machine, the metal container is separate from the remainder of the machine and is made of a material impervious to attack by aluminum, or protected against it. A ladle dips enough for one shot out of the container and the pouring well is charged only with the contents of the ladle. Between shots neither ladle nor pouring well is in contact with molten metal. For this reason it is much easier to keep

Dies for Typewriter Frame With Several Types of Cores. (Photo Courtesy Alcoa)



iron at a minimum — particularly important when high physicals are to be maintained.

The other chief difference between the methods lies in the *pressure* back of the metal when the die is completely filled and when the metal passes from the liquid to the solid state.

In the goose-neck machine, the pressure is limited to the mechanical strength of the cast iron goose-neck, 700 psi. being as high as is safe. In cold chamber, pressure casting machines, there is practically no pressure limitation, pressures as high as 10,000 psi. or even higher being sometimes employed. Usually, however, lower pressures (of the order of 3000 to 10,000 psi.) are used to simplify the mechanical problem of providing locking and holding power to keep the two die-halves together without opening up under the tremendous impact of the injected metal.

With the limited pressure back of the metal in the goose-neck machine, thin gates are required to fill the die rapidly and to force the molten metal through thin channels and over long distances before it freezes — analogous to the action of a garden hose where the nozzle opening must be restricted in order to increase the reach of the irrigating stream. Such thin gates are in danger of freezing before the shrinkage in the body metal has been completely compensated by feeding from the metal reservoir back of the gate. Furthermore, a thin gate promotes spraying of the metal into the body cavity; the metal enters in finely divided particles rather than in a steady stream, encouraging oxidation of the particles and entrapment of air. In a cold chamber machine, with its high pressure back of the metal, larger gates are generally feasible with their slower filling speed. The full available pressure is applied when the die is full of liquid, thus getting the benefit of more effective feeding of interdendritic shrinkages in the casting during solidification and of pressing the partially frozen body into sharp corners, crevices, and general contour lines.

However, cold chamber pressure castings are superior to goose-neck die castings only when made under expert metallurgical and production control, with careful consideration as to die or mold design in general, to venting and gating the molds, and timing of the various elements of the operating cycle.

Because of their uncertain structural condition, goose-neck castings should never be used in any application which bears any responsibility for maintenance of service or protection against trouble. Cold chamber pressure castings may be used for such services if produced under the controlled conditions mentioned in the preceding paragraph.

A recent development brought about by the demands of wartime has been the so-called controlled quality (pressure molded) aluminum, zinc and magnesium die casting. Controlled quality casting in metal molds is a variation of the ordinary cold chamber pressure casting in aluminum and magnesium, and of piston machine casting in zinc alloys, with especially rigorous production and metallurgical control, as well as stringent inspection and acceptance requirements. Controlled quality, pressure, metal mold castings can safely be used in critical and mechanically responsible structural applications where breakdown would mean serious interruption of important operations, danger to life, or failure to consummate critical objectives. They are of necessity more expensive than the commercial type of external pressure metal mold castings. Naturally, also, the number of vendors competent to live up to the requirements is limited. Controlled quality die castings should not be called for where commercial quality would be satisfactory or where other means of manufacture are more suitable. On the other hand, they offer the means of using castings of close tolerance, made at a high production rate, in place of permanent mold castings and wrought metal parts with considerable saving of strategically important material, man-hours and machine-hours.

The tolerances and general relative characteristics of various casting methods are given in Tables II and III. These tables are only broadly applicable.

The effect of process on the strength of the material is indicated qualitatively in Table III in the fourth line: "Strength (solid metal)". These estimates of strength should be considered in conjunction with the data on porosity in the same table because, for instance, a cold chamber pressure casting or pressure molded casting of a material of relatively low unit strength certainly will be more dependable because of the greater likelihood of internal porosity in a die casting made in a goose-neck machine. "Strength (solid metal)" refers to separately cast test bars, and — as outlined above — is more a figure for the maximum expectancy than the metal actually found in any casting of intricate shape.

Centrifugal Castings

The centrifugal casting process consists of pouring molten metal into revolving molds, and employing the centrifugal force so induced to form, compress, and cleanse the fluid metal.

The whirling mass forced tightly against the mold is cleared of gases by compression. Slag

Table II—Tolerances for Metal Mold Castings

(These data should be used for general guidance only. Actual design conditions will affect possible minima or maxima. See Note (a) for finishes)

ALLOY FAMILY	TOLERANCES WITHIN SOLID DIE (b)	MINIMUM WALL THICKNESS IN IN. (c)	MINIMUM HOLE DIMENSIONS (d)		MINIMUM DRAFT (e)
			DIAMETER IN IN.	MAXIMUM DEPTH, BY DIAMETERS	
Die Casting and Cold Chamber Casting					
Mg alloys	±0.0015, but at least ±0.003 in.	0.050 for small sections; more for larger areas	Smaller than $\frac{3}{32}$ $\frac{3}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored 3 times 3 to 5 times	0.010
Al alloys	±0.0015, but at least ±0.003 in.	0.035 for small sections; more for larger areas	Smaller than $\frac{3}{32}$ $\frac{3}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored 3 times 3 to 6 times	0.010
Zn alloys	±0.001, but at least ±0.0025 in.	0.015 for small sections; more for larger areas	Smaller than $\frac{1}{16}$ $\frac{1}{16}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Generally not cored 3 to 6 times 6 to 8 times	0.005
Brass & bronze	±0.003, but at least ±0.005 in.	0.050 for small sections; more for larger areas	Smaller than $\frac{1}{16}$ $\frac{1}{16}$ to $\frac{1}{4}$ $\frac{1}{4}$ to 1	Not cored 2 times 2 to 4 times	0.015
Permanent Mold Casting					
Mg alloys	±0.0015, but at least ±0.010 in.	0.1875, regardless of whether surface is rough or smooth	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{2}$ to 1	Generally not cored 3 times 3 to 6 times	0.015
Al alloys	±0.0015, but at least ±0.010 in.	0.125 (0.090 where at least one side can be reasonably rough)	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ $\frac{1}{4}$ to 1	Generally not cored 3 times 3 to 6 times	0.015
Bronze	±0.005, but at least ±0.010 in.	0.075 for small sections; more for larger areas	Smaller than $\frac{1}{4}$ $\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{2}$ to 1	Generally not cored 2 times 2 to 4 times	0.020

NOTES: (a) Metal mold castings can be finished with three different finishes, as follows, and should be marked on drawings to designate type of finish which is desired:

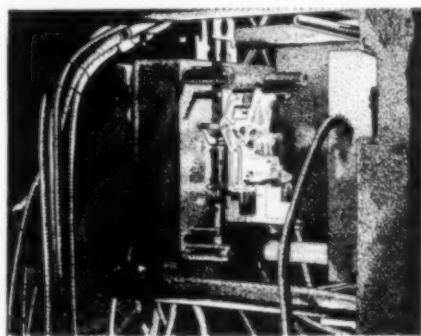
1. No marking—Commercial: Standard finish produced by commercial, but carefully controlled routine.

2. Decorative—(Required for plating.) Free from flow marks and from swirls and other surface imperfections.

3. Poorer than commercial—Suitable for unexposed or painted surfaces.

(b) Tolerances are expressed in in. per in. and should be as liberal as possible in the interest of low die cost and casting cost. Whenever permissible they should be greater than those given in the table. Closer limits are obtainable, but only at high cost. Tolerances affected by moving members, such as across parting lines, must be greater.

(c) Minimum wall section that can be cast with different alloys and by different processes is not absolutely fixed. It depends on the size and design of the casting, on the location of the section with reference to heavier adjacent sections, on the die, on the alloy (for example, an Al-Si alloy will cast



to thinner section than an Al-Cu alloy), type of machine and the pressure applied. In general, the lower the melting point and the more fluid the metal, and the shorter the distance the metal must flow between the chilling walls of the die or mold, or the faster it traverses the distance, the thinner the wall may be. There is practically no limitation on casting heavy wall thicknesses encountered in commercial applications. Sections somewhat heavier

than the minimum castable are recommended when die and pressure castings are to be plated, as they hold greater promise for smooth surface.

(d) Cores for casting holes produce a beneficial chilling effect; therefore, where possible, all holes should be cored, except when so small or deep that cores may be warped or bent under the shrinkage stresses of the freezing metal, or when drilling or punching is cheaper. The larger the hole, the greater the permissible depth.

(e) Draft is measured in in. per in. of depth of side wall or of holes. The draft, per side, on walls where the metal shrinks away from the die could be somewhat smaller. Liberal draft results in superior surface finish.

Table III — Relative Characteristics of Different Casting Methods
(Numbered in order of preference)

CHARACTERISTIC	SAND	CENTRIFUGAL (METAL MOLDS)	PERMANENT MOLD	DIE	COLD CHAMBER PRESSURE	PRESSURE MOLDED
Porosity	4	1*	2†	6	5	3 (a)
Surface	6	4†	5†	1	3	2
Sharpness of outline; tolerances	6	4†	5†	3	2	1
Strength (solid metal)	6	4*	5†	3	2	1
Thin section	6	4, as cast	5	3	2	1
Tool cost; pattern or molds (b)	1	2	3	4	5	6
Production speed and labor cost, per casting (b)	{ 1 (c) 6 (d)	2 (c) 4 (d)	3 (c) 5 (d)	4 (c) 1 (d)	5 (c) 2 (d)	6 (c) 3 (d)
Possibility to save machining	6	4†	5	3	2	1

NOTES: *In metal left after removal of drossy material from inside of wall of straight centrifugal casting.

†Only in material next to metal mold.

(a) In critical sections.

(b) Tool costs and cost per casting depend on the number of patterns per plate or impressions in die; the more castings that can be made at one operation, the lower the labor cost per

piece, with inversely increasing tool cost. Sand, plaster-of-paris and "investments" lend themselves more economically to multi-impressions than metal molds.

(c) On basis of most economical setup (as to number of impressions on one pattern plate or in one die) for comparative production quantities.

(d) For large production.

inclusions, oxides, and other impurities, being lighter than the molten metal (referring now to the cuprous and ferrous alloys) are squeezed out of the revolving mass and float on the surface of the metal nearest the axis of rotation. (This does not mean, of course, that dirty metal can be cast and the casting method depended on to clean it up!) For aluminum and magnesium alloys, however, non-metallic admixtures may, under certain conditions, show up in the otherwise most useful part of the casting, namely, the outer rim.

Centrifugal castings can be made in either refractory or metal molds. Metal molds are used mostly for high production.

Straight-walled centrifugal castings are generally and preferably limited in applicability to ring-shaped or tube-shaped castings with a straight, cylindrical bore concentric with the outside. Irregularly shaped inside bores may be produced by the use of cores. The outside surface may be round, square, hexagonal, octagonal, or any other symmetrical shape, straight or tapered longitudinally, with or without circular flanges or grooves. Occasional bosses, breaking the symmetry of the perimeter, can also be cast, provided they are not too thin or too high.

Straight centrifugal castings are sometimes produced without a central hole of any definite size, but material in or near the center axis, lacking appreciable centrifugal force, is quite apt to be porous, weak and to contain oxides and other non-metallic inclusions.

Castings without a hole through the center,

of practically any shape and contour, are produced by arranging them along the perimeter of a circle concentric with the axis of rotation. This method, properly known as "centrifuging" is much more adaptable than true centrifugal casting without sacrificing any of the structural advantages.

Practically all of the common metals can be cast centrifugally. The greatest production so far is in cuprous and ferrous metals, although light metals, particularly aluminum, are coming along fast.

Advantages of this method of casting are:

1. Dense, fine-grained structure is produced with uniform high physical properties; centrifuged castings are not subject to directional variations.

2. Waste metal in gates and sprues is practically completely eliminated in straight centrifugal castings with reasonably thin walls, and materially reduced in centrifuged castings.

3. True centrifugal castings can be made of considerable length, from which the required pieces can be cut in the same manner as from extruded sections.

The limitations of the method are:

1. In true centrifugal castings with a small center hole (thick wall), considerable metal on the inside of the bore must be machined out to remove oxides and non-metallic inclusions.

2. In true centrifugal castings, the outline must be symmetrical and concentric with the axis of rotation.

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Cold Finished Bars to Physical Property Specifications

are produced from the hot rolled bar stock and naturally inherit certain qualities. Cold finished bars are produced by two basic methods, namely: Cold drawing through a die or by cutting off the rolled surface. Either manufacturing procedure can be followed by centerless grinding, if extreme accuracy and fine finish are required.

The physical properties to be obtained on any particular size of bar are also dependent on the method

ASSIGNMENT of physical property specifications to cold finished steel bars was done to but a limited extent prior to the war. The economic success of these limited applications in the automotive, farm implement, machine tool and allied industries clearly indicated the widespread engineering possibilities that could be developed by a more general use in commercial applications. This statement is verified by the widespread use of guaranteed minimum physical properties for cold finished bars for ordnance applications, running into very large tonnage.

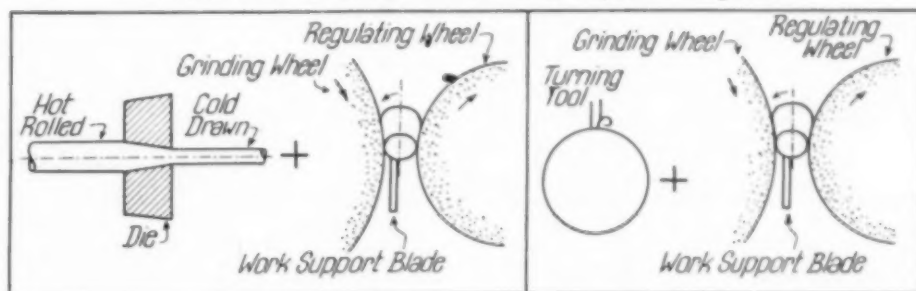
It is well recognized that the physical values of a steel bar of any given chemical analysis can be varied through a wide range by hot or cold work, combined with furnace treatments. However, the potentialities of the properties available in cold drawn bars (or cold drawn bars in combination with the various furnace treatments) have not been as generally understood.

Cold finished bars differ from hot rolled bars in that they have a smooth finish, close dimensional tolerances and improved machinability. However, they

of production. The properties of the turned and ground bars are those of the hot rolled bar, since turning does not change the physical properties of the metal. The same bars cold drawn through a die show an increased tensile strength and decreased ductility (elongation and reduction of area in the tensile test). This basic difference in physical characteristics, due to the method of production, is a fundamental consideration in the development of engineering applications. Figure 1 illustrates this comparison on 1-in. rounds from a same heat of hot rolled steel.

Heat treated material is produced either in the form of hot rolled or cold finished bars. A man-

Fig. 1 — Comparison of Drawn and Ground Bars Versus Turned and Ground Bars and Their Physical Properties



DRAWN AND GROUND	1-IN. ROUNDS OF C1137 OR X1335	TURNED AND GROUND
103,500 psi	Tensile strength	86,400 psi.
93,000	Yield point	54,600
56.3%	Reduction of area	61.0%
15.1	Elongation in 2 in.	27.3
217	Brinell hardness	180

Table I—Physical Property Changes Resulting From Variations in Cold Drawing Practices on a 0.40 Carbon Steel

	HOT ROLLED	COLD DRAWN WITH VARIED DIE PRACTICES		
Tensile strength	94,500	112,000	121,750	135,000
Yield point	63,500	97,000*	113,500*	129,000*
Elongation in 2 in.	30.0	14.1	11.9	10.9
Reduction of area	54.1	50.6	45.5	44.6
Impact	60	38	34	32
Brinell hardness	207	223	235	255

*Divider yield point.

ufacturing procedure including quenching and tempering, followed by turning or cold drawing, with or without subsequent strain relieving, has been generally used to develop definite engineering properties in the bar. This type of material is produced in a wide range of bar sections to specifications within the limitations of the mechanical and heat treating routine employed.

An available basic process that has not been so generally exploited is to cold work to varied intensity by die drawing, with or without subsequent reheating. Innumerable possibilities reside in variations of the per cent reduction by cold drawing, even without heat treatment.

Table I shows how an increase in tensile strength from 94,500 to 135,000 psi. can be obtained by the proper amount of reduction in a single grade of steel. With the addition of subsequent furnace treatments innumerable sound engineering specifications are possible in the various grades of steel—or even within the same grade of steel.

Tensile properties vary with the intensity of the cold work, which in turn is dependent on the amount of draft and the diameter of the bar. Table II shows this. "Intensity of cold work" is expressed as the percentage of area reduction resulting from varied drafting practices on different sizes.

We will now attempt to discuss some of the

Table III—Range of Properties in Hot Rolled Bars, ½ to 3 In. Dia., of C1137 and C1141 From Two Sources

	SOURCE A	SOURCE B
Carbon content	0.33 to 0.45	0.34 to 0.41
Silicon content	0.05 to 0.25	0.16 to 0.25
Grain size	2 to 7	2 to 7
Tensile strength	85,750 to 128,000	86,100 to 108,750
Yield point	50,500 to 77,250	53,550 to 75,200
Elongation in 2 in.	13.8 to 31.0	21.2 to 33.0
Reduction of area	25.1 to 61.1	41.0 to 64.4
Brinell hardness	170 to 217	170 to 207

broader aspects of the problem involved in setting up this type of specifications, and illustrate our remarks with details of some existing specifications for cold finished bars.

There are certain limiting factors which can be briefly summarized as follows:

1. Physical properties of the hot rolled bars. (Bar steel in the as-rolled or hot rolled condition is the basic raw material.)
2. Permissible cold work by die drawing.
3. Chemistry, as it affects response to cold work by cold drawing.
4. Furnace treatments subsequent to cold drawing.
5. Furnace treatments prior to cold drawing.

The Hot Rolled Bars—Bar steel in the hot

Table II—Per Cent Reduction in Area From Various Drafts

DIAMETER OF COLD DRAWN BAR	DRAFT (IN.)							
	½	⅓	¼	⅛	⅜	⅙	⅕	¼
½ in.	16	20	29	36	42	47		
¾	13	15	20.5	27	31.5	36	39.5	43
1	6	12	16	21	25.5	29	32.5	37
1½	4	8	11.5	15	18	22	24	27
2	3.6	6	8.8	11.4	14	18	19	21
2½	2.6	4.8	7.1	9.3	11.4	14	15.5	17.4
3	2	4	6.0	7.8	9.7	11.4	13	15
3¾	1.9	3.7	5.5	7.2	9.0	10.5	12	14

rolled condition is the basic raw material. It is evident, therefore, that all factors affecting their physical properties become basic limitations in establishing standards for cold finished bars.

To illustrate the possible variation, a series of tests on one grade from two sources is shown in Table III.

General uniformity of material is considerably higher from Source B than Source A delivered. Nevertheless these are the potential variations in the raw material which must be given consideration in establishing standards for the metal after cold drawing.

Two basic problems are involved. The first is the variation which may exist within the same heat. This is illustrated in figures from a single ingot of C1141 (Table IV).

The second factor is the effect of bar size in the same grade or chemistry. This is shown in Table V, wherein the bars were as received, without any heat treatment.

It will be noted that as the size increases all properties drop. Likewise, there is a variation in the tensile strength from 120,000 at top to 70,000 at bottom—30,000 to 40,000 psi. may be expected. On the assumption that these results are representative, the reason for the familiar heading "Average Results for a Given Size" in the published literature can be more readily appreciated. Unless controlled subsequently by some form of furnace treatment, the properties of hot rolled bars received from the steel mill will vary in proportion to the amount of hot working, the chemistry and segregation, the inherent hardenability and steelmaking practice, combined with the temperature of the last pass and the speed of cooling after rolling. Many of these variables are due to the physical layouts of the different mills.

The results in Table IV will evaluate two of the factors—the result of segregation and variable cooling rate of different sections of a single ingot. The results were obtained from bars as rolled from the top, middle and bottom billets of the same ingot. Of interest is the considerable difference in the Izod impact properties possible

Table IV—Variation in Physical Properties of Hot Rolled Bars From One Ingot of C1141

PHYSICALS	TOP	MIDDLE	BOTTOM
Tensile strength, psi.	108,750	102,000	99,350
Yield point, psi.	64,850	62,500	60,500
Elongation in 2 in.	22.5	26.9	28.2
Reduction of area	47.8	57.5	59.6
Izod, ft-lb.	40	55	60
Grain size	2 to 5	4	4 to 5
Deep etch	OK—slight pattern and pits	Good	Excellent

16%, the degree of elastic twist 30%, and the maximum shearing stress is increased 4½%. The cold drawn bar's maximum twist at rupture is on the average 23% lower than the twist that can be endured by the hot rolled bar.

This cold drawing effect can be modified over a considerable range by a variation in the draft and strain annealing. In addition to these changes in physical values, cold drawing also improves the inherent machining properties from 15 to 25%, especially in the softer steels. At the same time

the cold drawn bars are accurate, smooth, and free from hot rolled scale.

As stated previously, standard practice has been based on production limitations and ordinarily reduces the diameter ⅛ in. in cold drawing (sometimes ⅜ in.). The beneficial effect of heavier reductions, when followed by subsequent furnace treatments, has

apparently only been appreciated in recent years by producers and their customers.

As indicated in Table II the effect of mass in die drawing is important. It is obvious that a ⅛-in. draft on a 1-in. round (12% area reduction) works the steel more drastically than the same draft on a 3-in. round (4% area reduction).

The results of this mass effect can be appraised and interpolated from Fig. 2 to 5, discounting the identical furnace treatments, and bearing in mind the fact that a ⅛-in. draft on a ½-in. bar is a different amount of cold work than a ⅛-in. draft on a 2 ⅛-in. bar. The data were

Table V—Variation in C1137 With Size of Hot Rolled Bar

	½-IN. SECTION	1-IN. SECTION	3-IN. SECTION
Tensile strength	80 to 120,000	75 to 110,000	70 to 100,000
Yield point	45 to 75,000	40 to 70,000	35 to 65,000
Elongation in 2 in.	22 to 33	20 to 32	14 to 28
Reduction of area	38 to 60	35 to 56	31 to 53

in a single ingot of rather desirable tensile strength and ductility.

Table VI illustrates the expected commercial variations in physical properties of hot rolled bars of several chemistries. These figures should be taken into consideration when establishing standards based on cold drawing.

Cold Work Permissible—Recognizing the potential variations in the physical properties in the hot rolled bars, the next factor influencing standard specifications is the response to cold working as accomplished through die drawing.

This general effect of die drawing, as performed by a nominal draft of ⅛ in. on a 1-in. round (12% reduction) is to increase the tensile strength by about 19% and the yield point by 90%; the reduction of area in the tensile test is decreased slightly (about 9%) and the elongation in 2 in. is decreased sharply (about 40%). Torsional properties are also affected: The elastic shearing stress is increased

Table VI—Variations Possible in the Physical Properties of Hot Rolled Bars of Various Grades

GRADE	TENSILE STRENGTH	YIELD POINT	ELONG. IN 2 IN.	RED. OF AREA	BRINELL HARDNESS
C1035	60 to 100,000	35 to 75,000	20 to 40	30 to 60	120 to 180
C1045	65 to 105,000	40 to 80,000	17 to 35	30 to 55	160 to 220
C1137	70 to 110,000	45 to 85,000	17 to 35	28 to 55	165 to 225
C1141	75 to 115,000	50 to 90,000	17 to 35	28 to 55	170 to 225
A4140	80 to 140,000	50 to 110,000	14 to 30	30 to 65	160 to 320

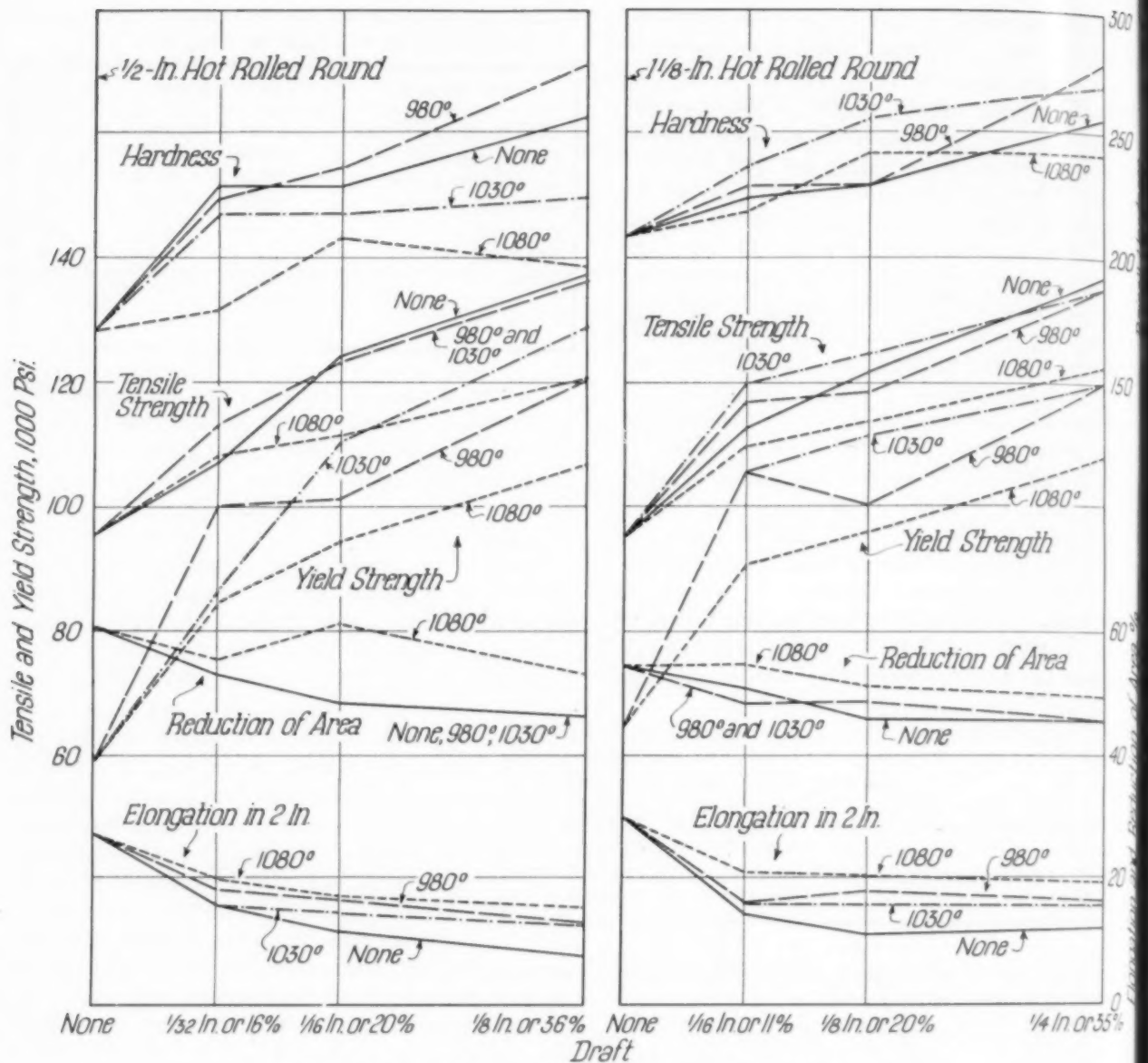


Fig. 2 and 3 — Effect of Draft and Stress Relief on Properties of $\frac{1}{2}$ -In. and $1\frac{1}{8}$ -In. Hot Rolled Rounds of C1137 (X1335)

assembled from tests made on grade C1137. Our experience has definitely shown that the higher carbon-manganese-sulphur steels, especially C1141 and C1144, are particularly amenable to the development of useful combinations

of physical properties by drafts heavier than normal. The results can be summarized by the changes in tensile strength as listed in Table VII which indicate clearly that as the bar diameter becomes larger, the gain in tensile strength resulting from a given draft decreases.

Table VII — Relative Change in Tensile Strength With Same Reduction on Different Bar Sizes

DRAFT IN COLD DRAWING	GAIN IN TENSILE (PSI.) AS IT VARIES WITH HOT ROLLED BAR SIZE						TOTAL VARIATION, PSI.
	$\frac{1}{2}$ IN.	$\frac{3}{8}$ IN.	$1\frac{1}{8}$ IN.	$1\frac{1}{4}$ IN.	$1\frac{3}{8}$ IN.	$2\frac{1}{8}$ IN.	
$\frac{1}{32}$ in.	12,000						
$\frac{1}{16}$	29,000	22,000	18,000	17,000	14,000	16,000	13,000
$\frac{1}{8}$	42,000	36,000	27,000	29,000	23,000	22,000	20,000
$\frac{1}{4}$			42,000	42,000	31,000	31,000	

ing from a given draft decreases.

Such results show that the specifications covering physical properties in cold drawn bars usually are varied with the size, the minimums being decreased as the size increases.

However, there are economic and practical limitations on the amount of cold

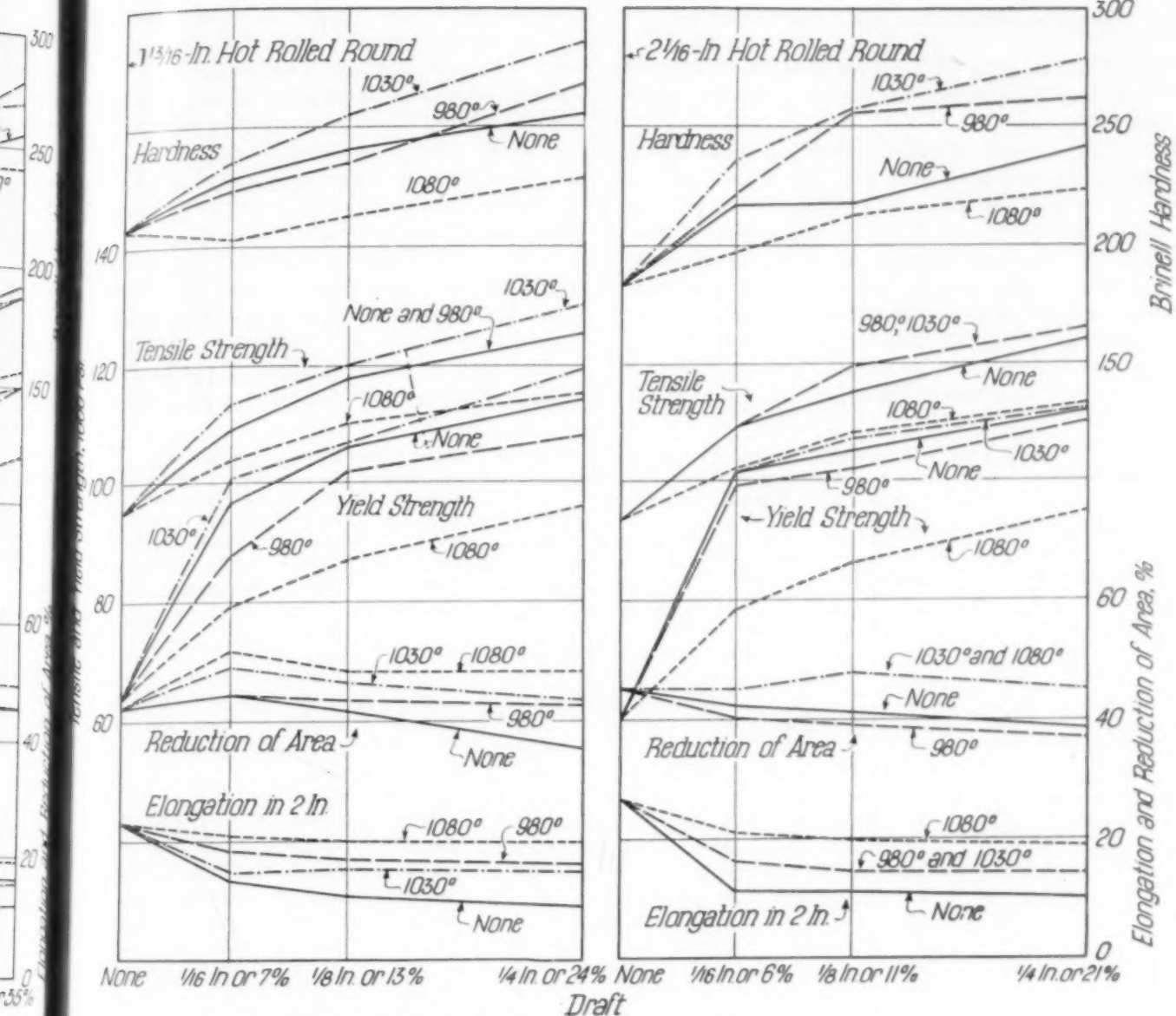


Fig. 4 and 5 — Effect of Draft and Stress Relief on Properties of 1 3/16 and 2 1/16-In. Hot Rolled Rounds of C1137 (X1335)

drafting. Special routines of die drawing and furnace treatments have also been patented. From a practical standpoint, the prime limitations are the occurrence of longitudinal cracking, production capacity, and the attendant problems. Occasional reference is made also to the possibility of internal transverse cracks as the result of die drawing, especially with heavier drafts. This is usually described as "bamboo". Of course, cold reduction must be kept below a point where internal rupture takes place. However, drafts even up to 1/4 in., dependent on the size of the stock, are not particularly heavy in percentage of area reduction when considered in terms of percentage reductions usually associated with the drawing of wire. For this reason internal transverse cracking is not a detrimental factor.

Effect of Chemistry — Those chemical factors which affect the hot rolled physical properties and the response to cold work determine the minimum specifications which can be met in a given chemical grade. The resulfurized grades with about 1 1/2% manganese (X1300 series) have been found to have a particularly desirable economic combination for obtaining excellent bar properties. Not only have they a desirable response to cold work, but also excellent free machining properties.

As might be anticipated, higher tensile strengths are available (within certain limits) as the carbon increases. The relative possibilities of the various carbon grades are indicated in Table VIII. It should be noted that figures given in this table are *average* results for comparative purposes, and should not be considered as minimums.

Furnace Treatments After Cold Drawing

The majority of cold finished bar specifications can be met by sub-critical annealing after cold drawing.

The general effect of reheating cold drawn bars can be deduced from Fig. 2 to 5, and is illustrated more particularly in Fig. 6. It will be noted that as the cold drawn bars are reheated, there is a marked increase in the tensile strength and yield point with the maximum effect in tensile strength at about 600° F. The elongation and reduction of area, however, are only slightly affected. As the temperature is increased beyond this point, the tensile strength and yield point

decrease while the elongation and reduction of area gradually increase until the properties of a fully annealed bar are reached. The exact amount of change is dependent on the analysis and the degree of cold working in cold drawing.

Using the tensile strength data as an example, it is evident that by furnace temperature regulation tensile strength can be controlled within limits impossible without furnace treatment.

The results shown in Fig. 2 to 5 illustrate the effect of sub-critical annealing treatments above the maximum hardening range on selected heats of steel of C1137 chemistry. The type of results shown in these figures, combined with data on the potential variation in the hot rolled

Table VIII—Average Physical Properties of Standard Carbon Steels in 1-In. Rounds

1942 A.I.S.I. SYMBOL	1941 S.A.E. SYMBOL	BRINELL HARD- NESS	TENSION PROPERTIES				TORSION PROPERTIES			
			TENSILE STRENGTH, PSI.	YIELD POINT, PSI.	REDUC- TION OF AREA, %	ELONGA- TION IN 2 IN., %	MAXIMUM SHEAR- ING STRESS	ELASTIC SHEAR- ING STRESS	DEGREE OF TWIST, MAXIMUM IN 10 IN.	DEGREE OF TWIST, ELASTIC IN 10 IN.
Cold Drawn, or Cold Drawn and Ground										
C1010	1010	129	60,000	54,200	62.7	20.6	58,000	29,400	2110	3.4
C1015	1015	140	67,000	59,400	61.3	19.0	61,200	31,300	2070	3.6
C1020	1020	148	74,050	68,750	59.4	17.2	62,700	33,600	1901	4.1
C1115	1115	160	78,600	72,500	53.5	16.0	67,300	35,100	1210	4.4
B1113	X1112	190	80,000	73,000	48.7	14.8	68,500	34,000	840	3.9
B1112	1112	190	83,000	76,000	50.2	15.1	71,200	34,700	970	4.2
C1019	—	156	80,750	72,600	60.7	17.2	68,800	35,200	1927	5.2
C1022	X1020	156	80,750	72,600	60.7	17.2	68,800	35,200	1927	5.2
C1117	X1314	156	79,500	75,000	60.3	16.9	68,400	36,500	1432	5.4
C1118	X1315	171	82,500	78,900	56.5	15.5	71,400	37,400	1376	5.6
C1025	1025	161	80,200	74,200	59.2	17.2	68,300	33,600	1605	4.6
C1030	1030	177	83,500	76,000	57.0	16.0	71,700	35,100	1520	5.2
C1035	1035	181	90,500	83,000	53.5	15.3	77,200	36,400	1445	5.7
C1132	X1330	191	93,250	85,000	58.3	16.4	82,100	36,600	1507	6.0
C1040	1040	192	99,750	92,000	54.6	15.1	85,600	36,000	1504	5.4
C1045	1045	202	102,500	93,450	52.5	14.8	86,400	36,800	1485	5.6
C1137	X1335	217	103,500	93,000	56.3	15.1	87,250	37,900	1620	6.4
C1141	X1340	228	110,300	99,000	52.7	14.8	91,000	38,200	1595	6.5
Turned and Polished or Turned and Ground										
C1010	1010	107	44,800	31,400	67.1	40.1	56,000	19,600	2220	3.0
C1015	1015	113	47,200	32,200	66.5	39.7	60,000	19,840	2175	3.0
C1020	1020	117	50,460	36,650	66.1	39.1	62,460	19,950	2109	3.1
C1115	1115	131	64,200	42,100	60.5	29.2	66,400	23,200	1510	3.0
B1113	X1112	150	63,000	41,000	55.7	26.5	59,300	21,709	1019	3.1
B1112	1112	142	65,000	41,100	57.1	27.1	66,200	23,000	1220	3.4
C1019	—	121	64,800	43,000	66.0	38.5	67,900	23,800	2129	3.4
C1022	X1020	121	64,800	43,000	66.0	38.5	67,900	23,800	2129	3.4
C1117	X1314	132	64,790	44,000	66.0	37.5	67,690	24,500	1664	3.4
C1118	X1315	132	67,500	45,100	61.0	33.0	69,900	25,100	1595	3.6
C1025	1025	131	61,000	38,300	64.8	35.0	65,200	27,200	2011	3.6
C1030	1030	140	72,000	44,100	63.0	31.0	71,200	29,400	1907	4.0
C1035	1035	150	79,100	48,500	60.0	30.0	76,000	34,200	1805	4.4
C1132	X1330	165	79,700	49,540	63.7	31.3	82,080	35,910	2208	3.7
C1040	1040	163	83,580	53,200	57.6	28.9	83,100	32,200	1761	4.7
C1045	1045	187	87,000	54,100	56.5	27.1	85,900	35,600	1740	4.9
C1137	X1335	180	86,400	54,600	61.0	27.3	85,100	36,100	1850	4.9
C1141	X1340	193	90,000	57,800	58.5	26.5	87,000	37,300	1830	5.0

bar, formulate a basis for establishing general standards which can be met as guaranteed minimums of physical properties in some particular size and chemistry. Of necessity, the minimum specifications should take into consideration the lower potential results obtainable in good commercial practice.

Conversely, where specific sizes are involved for specific constructional parts, elevated minimums are a possibility where the quantities and other production factors permit a closer control of the items affecting physical response to processing.

Higher strengths may be obtained by reheating after die drawing to temperatures within the range of maximum hardening, dependent on the amount of cold work.

Similar strengths may also be obtained by employing a heavier draft in the cold drawing, thus permitting slightly higher furnace temperatures for reheating. The latter normally results in greater uniformity of hardness, center to surface, freedom from distortional strains, and possibly improved ductility. These two general

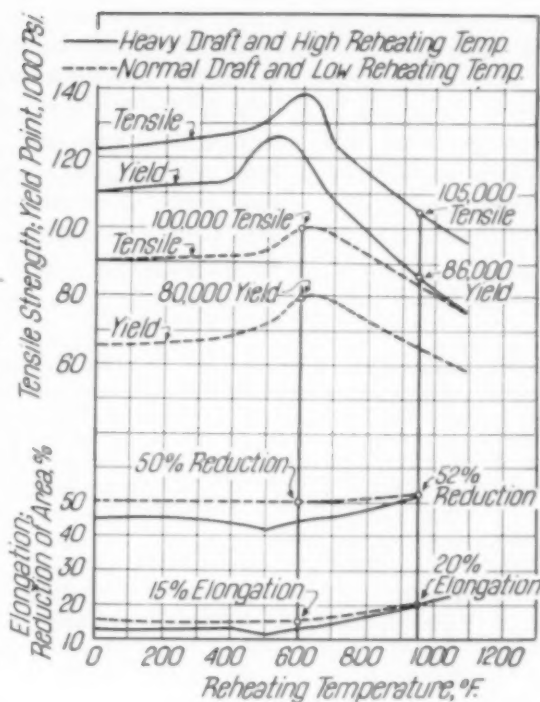


Fig. 6 — Effect of Drafting and Reheating on Properties of a Typical Cold Drawn Carbon Steel

physical properties by cold drawing and strain annealing, since the ordinary purpose of the alloy would be entirely lost if it were not developed by quenching and tempering.

Quenching and tempering has a limited field of application in the cold drawing art. Engineering standards are subject to the conventional metallurgical limitations such as the effect of mass, restricted machinability, and warpage. The structure developed after quenching and tempering does not lend itself

very well to cold drawing, unless the strength has been lowered considerably below that which can be developed by a quench and temper, and for this reason detailed statistics are not presented.

In general, heat treated bars are produced from the 0.40% carbon alloy grades by quenching and tempering, cold drawing, with or without a strain relief, or without cold finishing. The set of physical properties for heat treated bars shown in Table IX is typical.

Specifications

The widespread interest in and use of cold drawn and subsequently furnace treated bars is illustrated by the considerable number of current engineering specifications. The following general groups indicate the potential possibilities.

1. Ordnance requirements for

cold drawn steel to guaranteed minimum physical properties.

2. Suggested requirements on certain grades for cold drawn bars to guaranteed minimum physical properties in a full range of sizes.

3. Specific applications of physical property specifications to certain structural applications as produced by cold drawing and strain annealing.

Before outlining detailed properties, a few comments on hardness testing and yield strength are appropriate, as both lend themselves to complications on this type of product.

Table IX — Minimum Physical Specifications for Quenched, Tempered and Strain Relieved Bars

SIZE	TENSILE STRENGTH, PSI.	YIELD STRENGTH, PSI.	ELONG. IN 2 IN.	RED. AREA	BRINELL HARDNESS
Up to 2½ in.	125,000	105,000	16%	50%	321 max.
Over 2½ to 4 in.	115,000	95,000	16	45	321 max.
Over 4 to 6 in.	110,000	85,000	16	45	321 max.

procedures are illustrated in Fig. 6. The normal drafting procedure will give 100,000 psi. tensile, 80,000 psi. yield, 15% elongation and 50% reduction of area after heating to 600° F. The heavy draft will give 105,000 psi. tensile, 86,000 psi. yield, 20% elongation and 52% reduction of area after heating to 950° F. While these figures are on the same order of magnitude, the latter are distinctly better than the former.

Only carbon steels are considered in this outline as it would appear to be completely inappropriate to employ alloy steels for developing

Brinell or Rockwell hardness has frequently been found to be unsatisfactory as a basis of acceptance or rejection of cold drawn or cold drawn and strain relieved bar steel. It is not a direct measure of tensile strength. Experience has demonstrated that this product does not always follow the generally accepted linear relation between strength and hardness. This is clearly shown in Fig. 2 to 5. In general, hardness could be more appropriately employed as an "aim", and

from the straight line representing modulus of elasticity on the stress-strain curve. Other values, such as "proportional limit", "proof stress", or "elastic limit", are not really applicable to cold drawn steel bars and only to a limited extent on cold drawn and subsequently furnace treated bars. The above statements are based on the fact that cold drawn bars do not have the same type of stress-strain curve as heat treated, annealed or as-rolled carbon steels.

Table X — Minimum Specifications for Tensile Properties

SIZE	COLD DRAWN, NOT REHEATED				COLD DRAWN, FURNACE TREATED			
	TENSILE STRENGTH, PSL.	YIELD POINT, PSL.	ELONG. IN 2 IN.★	RED. AREA	TENSILE STRENGTH, PSL.	YIELD POINT, PSL.	ELONG. IN 2 IN.★	RED. AREA
C1137 (W.D. X1335 or Modified W.D. X1335)†								
Through $\frac{1}{8}$ in.	100,000	80,000	12.0%	35.0%	100,000	80,000	15.0%	45.0%
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	95,000	75,000	10.0	35.0	95,000	75,000	15.0	45.0
Over $1\frac{1}{4}$, through 2 in.	90,000	75,000	10.0	30.0	90,000	70,000	15.0	45.0
Over 2, through 3 in.	85,000	70,000	10.0	20.0	85,000	65,000	12.0	35.0
C1117 or C1118 (W.D. X1314, W.D. X1315)‡								
Under $\frac{1}{8}$ in.					75,000	65,000	15.0	30.0
$\frac{1}{8}$ to $1\frac{1}{2}$ in.					70,000	60,000	15.0	35.0
$1\frac{1}{2}$ to 3 in.					65,000	60,000	12.0	30.0
3 to $3\frac{1}{2}$ in.					50,000	40,000	10.0	20.0
Non-Resulphurized Bessemer Steel								
Under $\frac{1}{8}$ in.	75,000	65,000	12	30				
$\frac{1}{8}$ to $1\frac{1}{2}$ in.	70,000	60,000	12	35				
$1\frac{1}{2}$ to 3 in.	65,000	60,000	10	30				
3 to $3\frac{1}{2}$ in.	50,000	40,000	10	20				

*On sizes under $\frac{1}{8}$ in., elongation is to be measured in four times the diameter or $4\frac{1}{2}$ times the square root of area, either method optional.

†Made by coarse-grain practice as measured by McQuaid-Ehn test, either with silicon 0.10% max. or silicon 0.15 to 0.30% in killed

steel, as shell quality or special requirement quality.

‡Made by coarse-grain practice as measured by McQuaid-Ehn test, generally with silicon 0.10% max., usually killed steel in shell quality or special requirement quality, made with or without hot tops.

rejection or acceptance would be based on yield strength rather than on hardness.

This calls for a clearer understanding of yield strength or yield point which, unfortunately, means different things to different technicians. While various methods of determining the yield strength may be agreed upon, experience has indicated a "best" method adaptable to cold drawn and cold drawn and subsequently furnace treated bars, and is the method most generally employed. The procedure is to determine the value recorded at 0.005 in. per in. of gage length extension under load (0.01 in. extension under load in 2-in. gage length) with an extensometer or appropriate measuring device.

Yield strength by the so-called offset method might be substituted by special arrangement. It is measured as a 0.2% offset in a 2-in. gage length

Ordinance Requirements

Table X lists a number of physical specifications that have been applied to cold finished bar stock grades for ordinance applications as guaranteed minimums.

They are supplied both as regular cold drawn and cold drawn and strain relieved steels, with not more than the standard $\frac{1}{16}$ -in. draft, as shown.

Experience in the manufacture of steel to a number of the following specifications has justified their consistency and has proven that some of the figures which may seem to be low are proper when guaranteed minimums must be furnished to the customer.

Generally resulphurized bessemer screw stock is not supplied to guaranteed minimum physical properties except on special items where the

Table XI—Proposed Minimum Physical Specifications

COLD DRAWN, NOT REHEATED					COLD DRAWN, FURNACE TREATED			
GRADE AND SIZE	TENSILE STRENGTH, PSI.	YIELD STRENGTH, PSI.	ELONG. IN 2 IN.	RED. AREA	TENSILE STRENGTH, PSI.	YIELD STRENGTH, PSI.	ELONG. IN 2 IN.	RED. AREA
<i>Grade C 1040</i>								
Through $\frac{1}{8}$ in.	95,000	75,000	12.0%	35.0%	95,000	75,000	15.0%	45.0%
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	90,000	70,000	10.0	30.0	90,000	70,000	15.0	45.0
Over $1\frac{1}{4}$, through 2 in.	85,000	65,000	10.0	30.0	85,000	65,000	15.0	45.0
Over 2, through 3 in.	80,000	60,000	10.0	20.0	80,000	60,000	12.0	35.0
<i>Grade C 1137</i>								
Through $\frac{1}{8}$ in.	100,000	80,000	12.0	35.0	100,000	80,000	15.0	45.0
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	95,000	75,000	10.0	35.0	95,000	75,000	15.0	45.0
Over $1\frac{1}{4}$, through 2 in.	90,000	75,000	10.0	30.0	90,000	70,000	15.0	45.0
Over 2, through 3 in.	85,000	70,000	10.0	20.0	85,000	65,000	12.0	35.0
<i>Grade C 1045</i>								
Through $\frac{1}{8}$ in.	100,000	80,000	12.0	35.0	100,000	80,000	15.0	45.0
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	95,000	75,000	10.0	30.0	95,000	75,000	15.0	45.0
Over $1\frac{1}{4}$, through 2 in.	90,000	70,000	10.0	30.0	90,000	70,000	15.0	45.0
Over 2, through 3 in.	85,000	65,000	10.0	20.0	85,000	65,000	12.0	35.0
<i>Grade C 1141</i>								
Through $\frac{1}{8}$ in.	105,000	85,000	12.0	35.0	105,000	85,000	15.0	45.0
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	100,000	80,000	10.0	30.0	100,000	80,000	15.0	45.0
Over $1\frac{1}{4}$, through 2 in.	95,000	75,000	10.0	30.0	95,000	75,000	15.0	45.0
Over 2, through 3 in.	90,000	70,000	10.0	20.0	90,000	70,000	12.0	35.0
<i>Grade C 1144</i>								
Through $\frac{1}{8}$ in.	115,000	95,000	12.0	35.0	115,000	95,000	14.0	40.0
Over $\frac{1}{8}$, through $1\frac{1}{4}$ in.	110,000	90,000	10.0	30.0	110,000	90,000	14.0	40.0
Over $1\frac{1}{4}$, through 2 in.	105,000	85,000	10.0	30.0	105,000	85,000	14.0	40.0
Over 2, through 3 in.	100,000	80,000	10.0	20.0	100,000	80,000	11.0	30.0

required minimum properties are quite low.

Suggested Minimums—A proposed set of physical requirements for certain groups of cold drawn steels applicable where guaranteed minimum physical properties are required is given in Table XI. Carbon steels with 0.30 to 0.50% carbon are the generally accepted ones for minimum physical properties and constructional use, and the five grades of steels could be produced by normal drafting. Minimums could be guaranteed either with or without subsequent furnace treatments.

Specific applications of such specifications can be varied through a wide range, depending on size, grade, machinability requirements and quantities involved.

A specific example of a group to cover the engineering requirements of a particular product in a range of sizes is the following for C1137. The purchaser specified that sizes up to $1\frac{1}{8}$ in. should have a stress relief, thus giving the properties listed at the right of Table XI; for sizes above $1\frac{1}{8}$ in. he specified cold drawn (without stress

relief) thus giving the properties shown on the left side of the Table.

Table XI gives the properties after what might be called the normal drafts. Specifications obtainable by cold drawing and strain annealing bar stock in conjunction with heavier than normal drafts in cold drawing are summarized in Table XII.

Table XII—Minimum Physical Specifications for Bars Cold Drawn With Heavier Than Normal Drafts and With Subsequent Furnace Treatment

ANALYSIS	SIZE OF ROUNDS	TENSILE STRENGTH, PSI.	YIELD POINT, PSI.	ELONG. IN 2 IN.	RED. AREA	BRINELL HARDNESS
C1045	$\frac{1}{2}$ in.	135,000	105,000	8.0%	30.0%	240 min.
C1144	3	120,000	90,000	10.0	30.0	
C1050	$\frac{3}{4}$	120,000	100,000	10.0	30.0	255 to 302
C1050	$1\frac{1}{8}$	120,000	115,000	10.0	30.0	241 to 269
C1040	1	115,000	95,000	12.0	40.0	
C1137	$\frac{1}{2}$		90,000			
C1045	2		95,000			
C1141	$1\frac{1}{4}$		100,000			
C1137	$2\frac{1}{2}$		80,000			
C1045	$1\frac{1}{2}$	120,000	100,000	12.0	40.0	
C1141	$2\frac{1}{4}$	120,000	95,000	10.0	30.0	
C1144	2		100,000			
C1045	$1\frac{1}{8}$	115,000	90,000	10.0	35.0	

A Flux for Tin Bronze*

SOUNDNESS, working and mechanical properties of tin bronzes are improved by melting under oxidizing fluxes. In fact, the properties of metal prepared entirely from scrap are equal to those produced from virgin metals, provided the melting and casting techniques are suitable. Bronzes with 9 or 10% tin, melted under an oxidizing flux, properly deoxidized and cast so as to be free from shrinkage defects, can be extruded and subsequently cold rolled and cold drawn. Such wrought products have very high mechanical properties. Bronzes with 10 to 14% tin, so prepared, can be hot rolled or cold rolled. A 10% tin bronze extruded and cold rolled gave 168,000 psi. tensile strength and 18% elongation.

Flux composition, time of reaction between the flux and metal, composition of the thickener used

for removing the flux, and the deoxidation technique are all interdependent variables which may influence the properties of the metal.

The most suitable flux tested contained 34% borax, 50% sand and 20% cupric oxide. (Copper mill scale was found to be as satisfactory as technically pure copper oxide.) This flux does not attack the melting pots severely, is only slightly fuming at 2200 to 2400° F., and can easily be thickened for removal from the melt so slag inclusions in the metal are rarely found. The improved soundness and mechanical properties of the metal indicate that this flux also has a considerable degassing action. Common salt was found to be an objectionable constituent, and borax is preferable to boric acid. Pre-fusing the flux was preferable to using a dried mixture. The addition of the flux in two stages gave no advantage over adding it all with the charge. The time allowed for reaction between the metal and flux was restricted by the necessity of obtaining the correct casting

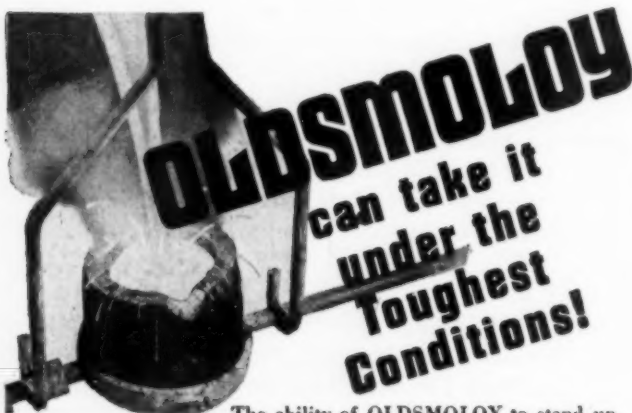
temperature and avoiding over oxidation.

Dried sand or fritted mixture of 3 sand to 1 borax or 3 sand to 1 sodium fluoride were the most satisfactory thickeners for this flux.

Aluminum rather than phosphorus used as a deoxidizer gives the bronzes higher densities and better hot rolling properties but seriously impairs the mechanical properties, particularly in the cast state, owing to the entrapped oxides. Residual phosphorus in these tests averaged 0.02% from an addition of 0.05%, while of the 0.1% aluminum used for deoxidation, only 0.01% remained, on the average.



*Abstracted from "Development of a Flux Degassing Process for Chill-Cast Tin Bronzes", by W. T. Pell-Walpole, *Journal of the Institute of Metals*, Vol. 70, 1944, p. 127.



Physical Characteristics

Tensile Strength—
70,000-76,000 psi

Elongation in 2"—
15% to 20%

Reduction in area—
21.70%

Proportional Elastic
Limit with Berry
Strain Gauge—
25,150 psi



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By Harry B. Osborn, Jr.
Director of Research
Tocco Division, Ohio Crankshaft Co.
Cleveland

Induction Heating and Heat Treating (A General Statement)

INDUCTION HEATING is so widespread that nothing more need be printed here other than some notes to clear up some points that seem to have confused metallurgists at times. It was E. A. Colby who first demonstrated that a conducting material could be placed in a non-conducting crucible, and made the secondary of a transformer and heat generated directly in it by induced electrical currents. The first successful melting according to this principle in America was in 1917 when Bridgeport Brass Co. installed the Ajax-Wyatt furnace, wherein current is induced in a submerged loop of molten metal by linking it through coils built into the furnace setting that take power from a normal alternating current circuit. Prof. E. F. Northrup of Princeton suggested the use of currents of much higher frequency, carried in a spiral of water-cooled conductors wound around a non-conducting crucible which held the metal to be melted — a principle first utilized in America by Baker & Co. for the melting of platinum — also in 1917. The energy source was a spark-gap oscillator, and applications were restricted by the small amount of power then obtainable from such a device. In the middle 1930's the Ohio Crankshaft Co., took advantage of the surface heating effect of higher frequencies and used motor-generators at 1920 and 3000 cycles for the surface hardening of crankshaft bearings. Shortly thereafter the Budd Wheel Co. became interested in induction heating for surface hardening the internal surface of tubular sections, the first gen-

eral application being that of an automobile axle hub.

Can Non-Magnetic Metals Be Heated? — So much for the historical background. Next some remarks are in order concerning the influence of magnetism on high frequency heating. In other words, what is the difference if you heat a magnetic piece of steel or a non-magnetic piece of aluminum? Bear in mind that *any* material which is capable of conducting a current, when placed within the confines of a conductor carrying alternating current, will become heated to a certain extent. The process is one of "induced resistance heating".

Since the substance which carries the induced current has the ability to act as a conductor, it also has an electrical resistance to the flow of energy. The major effect (even in magnetic iron and steel) can be attributed to the induced eddy currents, and the heat generated by magnetic hysteresis effects is comparatively of negligible importance.

However, the unusual characteristic of a *high* frequency current, upon which all surface hardening applications depend, is its tendency to concentrate on the surface of the conductor through which it flows. This phenomenon, called skin effect, is a function of frequency. Other factors being equal, the higher the frequency the shallower the depth of penetration.

When the temperature of an inductively heated magnetic steel bar arrives at a point where it loses its magnetism — the so-called Curie critical point, about 1420° F. — all heating due to hysteresis ceases and that due to eddy currents of a constant value continues at a reduced rate. The effective resistance of the load decreases as it goes through the critical. However, this resistance then may increase or decrease with temperature rise. Automatic control devices are available, if necessary, to change the current input proportionately to the above mentioned changes in resistances, so the heating rate may be kept substantially constant.

Since the entire action goes on in the surface layers, only that portion is affected. The original core properties can be maintained, and only the

Formulae for Resistance Heating

Compiled by Industrial Electronics Division
Westinghouse Electric Corp.

Load thermal power requirement

$$P_{kw} = 2.93 \cdot 10^{-4} MC \cdot \Delta F$$

Thermal loss from surface by radiation and convection

$$W_r = 37e \left[\left(\frac{T_1}{1000} \right)^4 - \left(\frac{T_2}{1000} \right)^4 \right]$$

$$W_c = 0.001 \left(\frac{5}{9} \Delta F \right)^{\frac{4}{3}}$$

Formulae for Induction Heating

*Power input into a non-magnetic cylinder

$$P_v = \frac{16.3 H_o^2}{d} \sqrt{f p} \cdot 10^{-7}$$

*Power input into a non-magnetic slab

$$P_v = \frac{8.15 H_o^2 \sqrt{f p} \cdot 10^{-7}}{t}$$

Depth of current penetration, non-magnetic conductor

$$\delta = 1.98 \sqrt{\frac{p}{f}}$$

*Power input into a magnetic cylinder

$$P_v = \frac{2.75 \cdot 10^{-4}}{d} \sqrt{f p} H_o^{\frac{3}{2}}$$

*Power input into a magnetic slab

$$P_v = \frac{1.37 \cdot 10^{-4}}{t} \sqrt{f p} H_o^{\frac{3}{2}}$$

Depth current penetrates in magnetic conductor

$$\delta = 1.98 \sqrt{\frac{H_o p}{B f}}$$

Coil voltage

$$E = H_o (2.86 \cdot 10^{-7} N A f K_2)$$

Coil current

$$I = H_o \left(1.43 \frac{1}{N} \right)$$

*Formula applicable only if depth of current penetration δ is less than half the thickness of the slab, or less than the wall thickness of a hollow cylinder which in turn is less than one-tenth the outside diameter of the cylinder.

surface layers hardened by quenching the part when complete carbide solution has been attained in those surface layers. Continued application of power causes an increase in depth of heating, for, as each layer of steel is brought to temperature, the current density shifts to the cooler layer beneath, which offers a lower resistance. Additional depth also results from the heat carried in by ordinary conduction, as the time of heating gets longer and longer.

It is obvious that the selection of the proper frequency and the control of power and heating time enable the metallurgist to fulfill almost any

Meaning of Symbols

A = cross-sectional area in coil, sq.in.

B = flux density in material in gaussses (usually assumed as 16,000)

C = specific heat of substance being heated

δ = depth of current penetration, in.

d = outside diameter of cylinder, in.

e = emissivity of surface (black body = 1)

E = coil voltage in volts (root mean square)

f = frequency in cycles per sec.

F = temperature, °F.

ΔF = temperature rise in °F.

H_o = peak magnetizing force in oersteds

I = coil current in amperes (root mean square)

K₂ = coil voltage factor

l = length of coil, in.

M = amount of material to be heated (lb. per hr.)

N = number of turns in coil

p = resistivity of work in micro-ohms-cm.

P_{kw} = load thermal power required, in kilowatts

P_v = power density in watts per cu.in.

t = thickness of slab, in.

T₁ = temperature, °K, of hot surface (°C + 273)

T₂ = temperature, °K, of cold surroundings

W_c = thermal loss in watts per sq.in. by convection

W_r = thermal loss in watts per sq.in. by radiation

desired specification of surface hardening, or of through heating for heat treating, annealing, normalizing, brazing, forging or forming.

Dielectric Heating

Next, some confusion exists as to the nature of dielectric heating—the heating of non-conductors by high frequency currents. Although this is a non-metallurgical operation, a few words may not be amiss. Dielectric heating dates back to 1864 when it was observed that the insulation in condensers became warm. "Capacitors", as condensers are called today, are of great value in ordinary alternating current circuits for improving the power factor, and so much heat is generated in the insulating fluids in them that special cooling devices have to be incorporated. While the physician had long been applying ultra high frequency for diathermy treatments, an industrial application of the process was not recorded until about 1936 when the Thermal Engineering Corp. became interested in a process for evaporating the moisture from tobacco without removing it from the hogsheads in which it was packed and shipped.

As already explained, induction heating of metals (conductors) depends primarily on the quantity of current which is induced to flow through the cross section or a portion of it, and the rate of heating is in direct proportion to the square of the current. In dielectric or electro-

static heating of non-conductors or insulators, the rate of heat developed is related to the field intensity and depends upon the voltage and frequency, as well as the so-called dielectric characteristics of the material. The energy produced is proportional to the square of the voltage.

Another fundamental difference is in the equipment. With induction heating there is no physical contact between current carrier (inductor coil) and metal being treated. With dielectric heating, on the other hand, high frequency at high voltage is generated across plates which are in contact with the non-metallic material being heated; there is no skin effect and the heat is generated almost uniformly throughout the cross section of the mass existing between equivalent areas of electrode plates.

Lastly it may be mentioned that efficient dielectric heating requires frequencies up in the millions of cycles per second.

Relations Between Frequency, Diameter and Penetration

Mathematical physicists have worked out equations that purport to calculate minimum optimum frequencies for specific work, but such equations do not prove correct in actual practice. For example, such equations would indicate the need for frequencies of several hundred thousand cycles for processing of 1/2-in. diameter stock, whereas stock smaller than this is actually being efficiently heated with 9600 cycles.

The type of material to be heated in no way determines the frequency requirements. Considering a given diameter of solid stock of a given material (steel, copper, brass, or aluminum — all conductors), if the frequency is sufficiently high so that the diameter will permit good efficiency response, little is gained in conversion of kilowatts to thermal units by a further increase in frequency. This is a most important point to remember, since it has been erroneously thought by many that the heating of non-magnetic materials requires higher frequency than steel. As pointed out, this is not true.

There is, however, a relationship between frequency and diameter. Half-inch diameter stock processed with 2000 cycles would heat substantially through its entire cross section and permit little if any surface hardening, whereas with 9600 cycles a hardened depth of 0.080 in. is generally obtained. Even shallower depths can be had with excessive power inputs per unit of surface area (for rapid heating) or with higher frequencies.

In other words, time and power input influ-

ence the practical applications. Thus, a highly localized surface effect can produce heat enough for a relatively thick part if the current is retained a long time and the surface heat soaks into the center — exactly as it would if the metal were heated in a conventional furnace. (Obviously, there are limitations since the temperature differential created by, say, 500,000 cycles on a 2-in. bar would make it most impractical to use this frequency for through heating such stock.) In a contrary direction, a relatively low frequency will have a highly localized surface effect if an unduly large amount of power is pumped into it for a relatively short time.

Assuming reasonable metallurgical response of the original structure and equivalent current density, the following table shows the absolute minimum depths of hardness which should be considered for production work in the hardening of steel:

FREQUENCY, CYCLES PER SECOND	APPROXIMATE MINIMUM PRACTICAL DEPTH OF HARDNESS	THEORETICAL DEPTH OF PENETRATION OF ELECTRICAL ENERGY*
3,000	0.060 in.	0.035 in.
9,600	0.040	0.020
120,000	0.030	0.006
500,000	0.020	0.003
1,000,000	0.010	0.002

The data on depths of hardness in the middle column represent actual results obtained with microstructures which respond very readily to heat, and are values noted with both single and progressive methods of treatment with power input considerably greater than theoretically required. Obviously, the diameter of the stock must be sufficient to offer a reasonable core, since flow of heat in steel from the surface inward is so rapid that regardless of frequency or power, material of less than 1/8-in. diameter cannot be surface hardened. A similar condition exists with tubing; wall thickness should be at least twice the depth of hardness anticipated.

Fullest advantage of the skin effect of high frequency heating is obtained only if the surface area can be brought up to hardening temperature

*The figures in the last column are computed from the empirical equation for heating steel to 1500° F. in zero time:

$$D = \sqrt{\frac{4}{F}}$$

where *D* is the depth of penetration of electrical energy in inches, and *F* is the frequency in cycles per second.

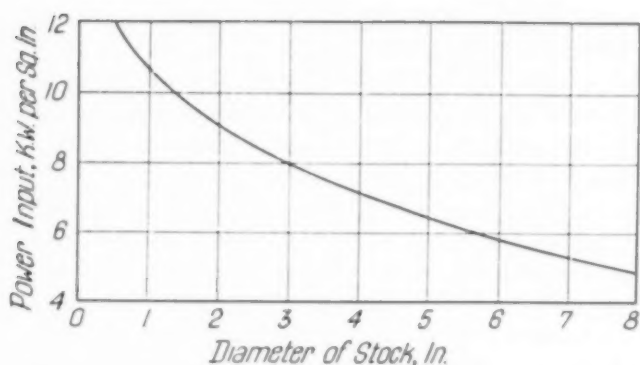
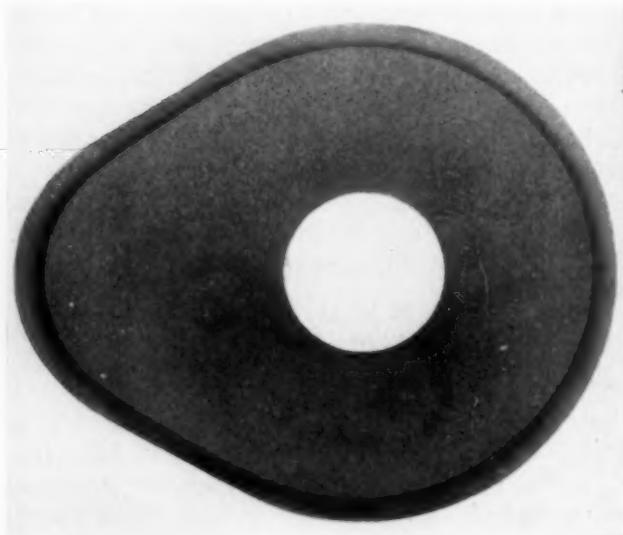


Fig. 1 — Suggested Minimum Power Inputs per Unit of Surface Area for Maintaining Depths of Hardness Usually Associated With Frequencies Employed. Modifications are necessary, dependent upon response of metallurgical structure to solution and diffusion

in a few seconds. To do this we must maintain certain minimum values of power input per unit of surface area; otherwise flow of heat inward by thermal conduction will increase the depth of hardness unduly. Minimum values are suggested in Fig. 1. On extremely small diameters power inputs of 30 to 40 kw. per sq.in. of surface area and frequencies of well above 100,000 cycles are generally required. (Time cycles for single area processing are established on a basis of 30 to 35 kw.-sec. per sq.in. of surface area.)

For brazing or forging work where deep heating of sections is necessary, we generally introduce power of the order of 2 kw. per sq.in. of surface area on $\frac{1}{2}$ -in. stock, 1 kw. per sq.in. on 1-in. stock, $\frac{1}{2}$ kw. per sq.in. on 2-in. stock — or, roughly, a kilowatt input per sq. in. of surface

Fig. 2 — Photomicrograph (Full Size) of Cam From Diesel Engine Camshaft Showing Contour of Hardness Obtained With Round Inductor Block, Current 3000 Cycles



area equal to the reciprocal of the diameter in inches. Obviously, modifications of these factors are necessary depending upon the uniformity of cross section, upon shape, and some other minor variables.

Energy conversions show values of from 5 to 15 lb. of stock heated per kilowatt hour of high frequency energy input depending upon temperature, which will range from 1100° F. for brazing to 2200° F. for forging.

Non-Cylindrical Parts

Next, some remarks on the heating of non-cylindrical parts may be made. The skin effect of high frequency current from a round inductor holds the induced energy to the surface of the object being heated, as is clearly shown in Fig. 2 and 3. Other things being equal, the higher the frequency, the greater this tendency of the current to hug the surface, but as we depart from

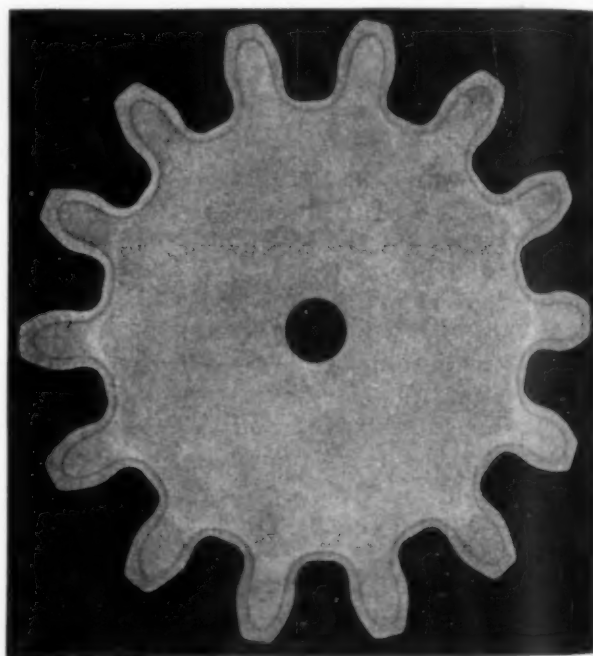


Fig. 3 — Ideal Contour Hardening Obtained on Coarse Pitch, $4\frac{1}{2}$ -In. Diameter Spur Gear, Using Round Inductor and 450,000 Cycles at 60 Kc.

cylindrical surfaces we are unable to maintain this uniform depth of heating. A gear is nothing more than a cylinder with distorted surface and while higher frequencies are advantageous for contour hardening, a high power input and short time is needed even more, to prevent heat flow by conduction throughout the entire cross section of the tooth. Commercial limitations of the power available from very high frequency equipment therefore limit such processing to small gears.

Further, perfect contour hardening is limited to gears of less than approximately 7 pitch, regardless of frequency. On finer pitches, essentially the full cross section of the teeth hardens. However, gears so processed perform satisfactorily in transmissions and in other assemblies.

For large sprockets and similar parts it is generally better to use a formed inductor and process one tooth at a time. Care must be taken so the demarcation zone, at the surface, between hardened and unhardened areas falls outside of highly stressed fillet areas.

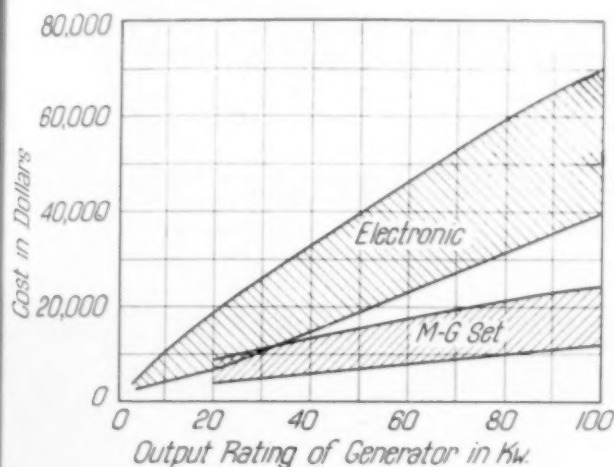


Fig. 4 — Comparison in Cost Versus Output Rating of High Frequency Equipment, Vacuum Tube Oscillators and Motor-Generator Sets. Approximate generator costs including accessories. (Courtesy Westinghouse Electric Corp.)

Internal Hardening

Finally, the requirements for hardening internal bores may be briefly stated.

It is not considered practical to internally heat diameters under $\frac{3}{4}$ in. due to limitations of inductor design and cooling. While a simple loop of copper tubing or a helical coil may be a satisfactory inductor, its efficiency is so poor that its use is restricted to applications permitting long heating cycles. The use of powder iron or laminated iron cores inside the inductor is essential for shallow surface hardening, particularly of thin walled parts.

With such inductors we harden the bore of cylinder liners, gun barrels, wheel hubs, pump lines, dies, and similar shapes.

Some steels are heated internally for forging, as are also a large number of assemblies which are inductively brazed. Many times the expansion from the inside of an assembly, as produced by internal heating, is an advantage in producing tighter joints.

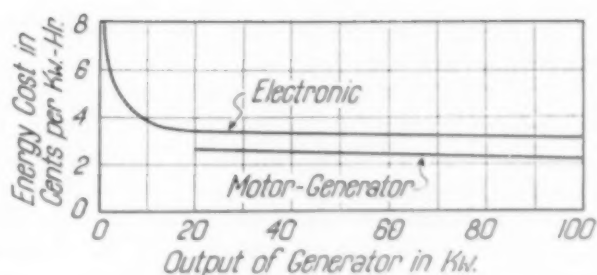


Fig. 5 — Comparison of Energy Cost in Cents per Kilowatt-Hour Versus Output of High Frequency Equipment, Vacuum Tube Oscillators and Motor-Generator Sets. Approximate high frequency energy cost including tube replacement, maintenance, amortization and power. (Courtesy Westinghouse Electric Corp.)

The metallurgical considerations, energy requirements, and other factors are the same as for external heating.

Power Sources

The foregoing paragraphs obviously apply to high frequency currents, and anything said therein is independent of the source of such currents. Most power circuits in America are standardized at 60 cycles per sec., and this is suitable for direct use in a brass melting furnace of the Ajax-Wyatt type, for stress relieving, and for some heating for forging. (There are limitations, even here, which involve such items as power factor correction and size of equipment.)

The very term "high frequency" heating means that this line-frequency must be stepped up very considerably. There are three reliable methods of doing this; the choice depends solely on economy, and this is related to the frequency, the amount of power required, and the maintenance and overhead costs. Many of the questions involved have to do with problems in advanced electrical engineering, and consequently are outside the scope of an article devoted to metallurgical considerations.

Of the three sources the motor-generator and the spark gap oscillator are confined to the induction heating of metals, and the third, the vacuum tube oscillator, is used for both induction heating and dielectric heating.

Motor-generator sets, commonly referred to as rotating equipment, are produced by manufacturers of electrical power equipment as standard units up to 1500-kw. output at frequencies of 960, 1920, 3000, and 9600 cycles. Such units are powered by synchronous or induction motors operating at either 1800 or 3600 r.p.m. from standard 60-cycle power lines. The operating efficiency runs generally at 75% to 85%. There

is no power limitation; they can be used for hardening extremely large parts if necessary, and motor-generator units can be, and are frequently in practice, paralleled for high power output.

Smaller units of the spark gap oscillator type provide frequencies of the order of 100,000 to 400,000 cycles; usual ratings are for 7½, 15, 32, and 40 kw. input. The output from the largest single machine is comparatively small and generally limits this type of equipment for the hardening of small parts, if the heating time is to be kept short and full advantage taken of the high frequency energy.

Frequencies of several hundred thousand cycles are developed by means of vacuum tube

oscillators, but power output is again a limiting feature with 15, 20 and 50-kw. output appearing as standard equipment. Frequencies generally used for induction heating run from 350,000 to 500,000 cycles with a few special units at 1,000,000 cycles. For dielectric heating, oscillators running from 2 to 30 megacycles represent the major type. A few units are used at 100 megacycles, but at low power levels.

The cost of the power plant and the cost of energy delivered to the work are both items that have considerable importance in any commercial heating process. Figures 4 and 5 on page 865 are taken from publications of the Westinghouse Electric Corp., and speak for themselves.

Important Achievements of Induction Heating

Frequencies Up to 10,000 Cycles

By Harry B. Osborn, Jr.
Director of Research
Tocco Division
Ohio Crankshaft Co.
Cleveland

OVER 300,000 kw. of induction heating equipment is in operation today in countries all over the world despite the fact that the equipment was not actually perfected until less than ten years ago. Its ultimate utilization for the heat treating and selective hardening of metals, heating for forging and forming, and brazing or soldering of similar or dissimilar metals challenges the imagination. The demand for war matériel has extended the use immensely; likewise a majority of our trench mortars, rockets, chemical and smoke shells were designed to take advantage of high frequency heating for brazing of the various shell assemblies, permitting simple design and facilitating production. Undoubtedly these trends will persist into peace-time.

A vast majority of the work is done with frequencies of 9600 cycles per sec. or less, generated by motor-generator sets connected

Frequencies From 100,000 to 500,000

By Jules J. Fox
Lepel High Frequency Laboratories
New York City

WITH the easing of war-actuated pressure on manufacturing methods and processes, the opportunity arises to appraise some of the more modern developments in their proper perspective. One of the outstanding of these developments has been the application of high frequency induction heating to a multitude of metal processing operations, with a consequent improvement in the quality of the final product, usually accompanied by a marked reduction in costs and simplification of labor problems, and with material handling facilitated to a degree that is nothing short of remarkable.

In making a selection of equipment, and applying it to his present and future needs, the prospective user is confronted by a number of problems. Shall he select equipment operating in the range of 2000 to 9600 cycles (intermediate between power line frequencies and really "high" frequencies), shall he select the high frequency range of 100,000 to

Vacuum Tube Units

By J. Wesley Cable
Director of Research & Development
Induction Heating Corp.
New York City

MOST of the important aspects of high frequency current for a metallurgical heating medium have been clearly presented by Messrs. Osborn and Fox in articles presented alongside this one. However, it is worthy of emphasis that the frequency of the current is not a critical factor in most industrial heating for hardening, annealing, brazing, welding or shrink-fitting. Sizes and shapes of most modern machine parts being what they are—that is to say, carefully engineered parts requiring heat treated carbon or alloy steel to carry the loads—I dare say that 80% of induction heating applications involving high frequencies can be done at either 10,000 cycles or 375,000 cycles without any noticeable difference in the resultant product, or of capacity of the equipment involved. The other 20% includes a certain group of applications involving large masses and large diameters that inherently indicate low frequencies, 10,000 cycles or

10,000 Cycles

to ordinary commercial power circuits. Through heating of sections, several inches in diameter, is only practical in large scale production with motor-generator frequencies in this range, particularly if temperatures are high, as for those used in forging. Also of outstanding importance, economically, is the fact that the motor-generator frequencies are obtainable at the lowest cost per kilowatt. (See Fig. 4 and 5 in the preceding general statement.) In other words, an installation involving 2000 kw. of high frequency equipment would cost approximately \$100,000 with a motor-generator unit, but would be close to \$600,000 with vacuum tube oscillator equipment or even with spark gap equipment, if anyone would want to manufacture such a large unit. (See Fig. 4.)

Space requirements are also of importance. A 200-kw. motor-generator set would be only approximately 2x2x5 ft. in size, whereas a 100-kw. tube oscillator would require a room at least 10x20x10 ft., due to spacing limitations and insulating the various pieces of equipment in the circuit.

One outstanding advantage unique with the motor-generator equipment is that the inductor coil and accompanying condensers can be mounted hundreds of feet away from the generating unit. A single large motor-generator can therefore be installed for energizing a large number of heating stations scattered throughout a plant, transmitting the current by bus bar, coaxial cable, or standard four-conductor cable with the two opposite legs tied together. Dangers to the generating equipment from the omnipresent dirt in forging plants, for example, are eliminated by completely water-cooled units in a tight case, safe for installation in the most unfavorable locations. Since heating for forging is generally done with very rugged motor-generator machines (such are absolutely necessary for heating heavy sections) the problem of vibration due to hammer operation is very seldom encountered.

All induction heating equipment is provided with interlocking devices for protecting the operators, so that no hazards are involved. (Continued on page 808)

100,000 to 500,000

500,000 cycles, or the ultra-high frequency range above 1,000,000 cycles? Shall he select motor-generator, spark-gap, or vacuum-tube actuated units?

Unless some very special problems are to be encountered, the chances are that equipment operating in the range from 100,000 to 500,000 cycles will prove to be most satisfactory. At least that is the belief of 11 of 14 leading induction heating manufacturers, for they build their equipment to operate within this range.

Experience by users indicates that the 100,000 to 500,000-cycle range affords a number of very definite advantages. It has the ability to follow the irregularly shaped contours of gears and splines fairly evenly; it affords satisfactory control of the depth of penetration; and has no marked difficulties in the generation or the handling of power. Heating of thin sections, and surface hardening of small diameters, which cannot be handled satisfactorily at the intermediate frequencies, are easily performed with the higher range. As a matter of fact the number of small machine parts that are heat treated is vastly greater than the really large ones; the tendency of modern design is to cut down size, not only to save raw material and space, but to reduce inertia and frictional effects.

The ultra-high frequencies, on the other hand, whose main theoretical advantage is that they permit extremely shallow depth of hardening, present increasingly difficult problems in the generation and handling of the power as the frequency increases. Load coil sizes have sharply defined limitations, with very high voltages utilized at load coil, and loosened coupling is frequently required to avoid flashover to the work.

Various recent articles have discussed the fact that the heating effect in metals placed in proximity to a current-carrying magnetic field is occasioned by the total of the hysteresis and eddy current losses produced (in ferrous material). It should be borne in mind that hysteresis losses are engendered in ferrous material while in the magnetic state, and that these losses cease when steel and iron parts are raised (Cont. on p. 810)

Tube Units

even lower, and there is a corresponding group of applications involving small diameters and thin sections, or the heating of extremely thin surface layers that dictate high frequencies ranging from 100,000 to 500,000 cycles.

Three advantages are gained in the use of higher frequencies.

The first is the ability of the higher frequency energy to concentrate the heat in thinner layers on the surface of the piece. Figure 1c shows that the theoretical value of electrical penetration at 10,000 cycles is approximately 0.020 in. in steel (Point A) with a

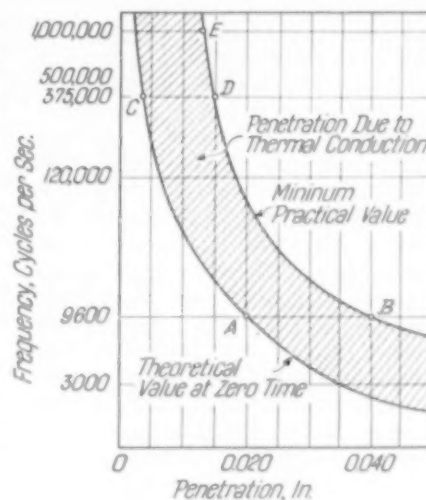


Fig. 1c — Penetration of Heat by Different Frequencies. Time and other conditions constant (Benninghoff and Osborn)

minimum practical value of 0.040 in. (Point B) as a result of thermal penetration by conduction. Correspondingly, the theoretical value at 375,000 cycles is reduced to about 0.004 in. (Point C) with a practical minimum of approximately 0.015 in. (Point D). The manner of utilization of this phenomenon is quite evident since the surface hardening of metals to thin surface layers naturally indicates the use of this higher frequency. Whether a thin hard layer will be sufficient — even on a comparatively large part — must be decided by an analysis of the individual part, backed up by service experience or comparative test runs. Generally the ruling considerations will be the same as for case carburized parts, with the undoubted trend toward the thinner cases. (Cont. on p. 813)

10,000 Cycles

Continuous Heating of Bar Stock

So much for the electrical methods of generating current up to 10,000 cycles. Of most immediate interest is a brief account of some recent advances in the use of such current that will be available to post-war industry.

Certainly one of the most important is the continuous heat treating of bar stock wherein material is heated to hardening temperature, quenched, and reheated for drawing. This uniform product shows so many advantages and economies that this will no doubt be a "must" for all steel mills in the country making a quality product. Each bar will have a uniform microstructure end to end, and no conventional furnace has ever been built which could pick up a bundle of bars and heat and quench and draw each one uniformly at the same rate. There is no comparison as to quality, but the unusual thing is that the overall heat treating cost with induction heating, including power, labor, and overhead, is about \$15 a ton compared to the \$30 standard charge by all mills for heat treating.

A notable installation for hardening and tempering bar stock is shown in Fig. 1a. While this is for through hardening, equipment for surface hardening stock (such as shown in Fig. 2a) is also available; it uses higher power input per unit of surface area and faster rate of travel. Selection of the rate of travel of various diameters depends somewhat on the width of the inductor, and also on the depth of hardening desired. Figure 3a serves as a guide for depths mentioned in the table reproduced on page 803 in the preceding general article.

Bars through heated for forging or hardening are generally processed at a rate of approximately $\frac{1}{4}$ to $\frac{1}{2}$ in. per sec. Tubing, on the other hand, may be hardened at speeds ten times this value. See Fig. 4a. Limitations are imposed by metallurgical requirements depending on analysis and structure. For sluggish steels, whether being hardened or annealed, time at temperature is an important factor. The use of



Fig. 1a — Typical Plant Installation for Continuous Heat Treating of Bar Stock. Each handles 250 lb. per hr., quenched and drawn to specifications. Fixture is adjustable for $\frac{1}{2}$ to $2\frac{1}{2}$ -in. diameters

several inductors in a row permits adequate soaking time and still maintains production rates.

Localized Heat Treatment

An outstanding example of localized heat treatment was described by Fred M. Arnold in an article on "Steel Cartridges of 3-In. Caliber" in *Metal Progress* last January, page 67. In order that these cartridges, made of plain carbon steel, may have sufficient strength near the base, $3\frac{1}{4}$ in. of the side wall is heated by moving it through an inductor coil at a variable rate closely controlled to fit the variable side-wall thickness (tapering from about 0.56 to 0.20 in.). The fixtures and controls for this job are masterly pieces of work, and are described

in complete detail in the article mentioned.

This application illustrates the outstanding characteristic of induction heating. Properly engineered it produces the maximum degree of reproducibility. Automatic control and accuracy are keynotes in induction hardening from two standpoints. First, because of precise design of equipment, there is automatic positioning, assuring exact locations of hardened areas (more than one area can be treated simultaneously), and automatic control of heating, quenching, and indexing cycles accurate to within 0.1 sec. Second, this control makes each heating operation and treated object an exact duplicate of all others processed with the same setup, limited only by the degree of uniformity in the steel being processed. Further, total elimination of human error avoids the usual variations and mistakes so characteristic of manual control.

Heating for Forging

Use of induction heating for forging shells, bombs, propeller hubs (both steel and aluminum), and upsetting gun tubes was limited in war-time only by the amount of equipment that could be allocated for the purpose. The great success warrants belief that it will be widely adopted for peace-time uses. Advantages are high production rates, low operating cost, reproducibility of a uniform temperature (or a graded temperature at will), lack of scale due to rapid heat, and accompanying increase in die or tool life.

In general, for high production work, slugs are passed continuously through the inductor coil, which may be horizontal or vertical. In this manner, the material is brought up to temperature gradually and uniformly throughout its entire cross section. Small slugs may be passed through inductor coils lined with quartz tubing; heavier slugs, on the other hand, are supported on water-cooled guides. Vertical heating coils serve for medium and heavy weights wherein the guides need only position the slug without supporting the entire weight as the parts are moved upwards.

Installation cost of the equipment, as well as operating cost based on energy only, will be

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three or four times that of a stand-
ard fuel-fired furnace. Use a fac-
tor of \$15 per lb. of metal heated
per hr., based on a conversion of
5 lb. per kw-hr. for heating steel
to 2000° F. when estimating the
cost of the equipment, installed.
Operating cost for electrical
energy is approximately \$4 per
ton of steel heated per hr. For
example, an installation suitable
for heating one ton of stock per
hour to forging temperature would
cost approximately \$30,000, and
the operating cost for electrical
energy would be \$4 per hr. The
unit can be completely mecha-
nized by magazine hopper feeder.

To counterbalance these rather
high costs of equipment, induction
heating makes fuller use of presses,
upsetters, or forges by furnishing
a continuous stream of heated
parts. Actual all-over operating
costs are really less than for
other heating methods if we take
into consideration that power is
used only when material is being
run, there being no stand-by
charges, no waste energy for
bringing the furnace up to tem-
perature or energy dissipated
when it cools, no expensive venti-
lating system, and no stand-by
crews. Count in also the advan-
tages of accurate temperature con-
trol and a minimum of floor space.

The above figures and dia-
grams are based on the heating of
steel. Heating of aluminum to
950° F. or brass and copper to
1600° F. is accomplished at a con-
version of approximately 8 to 10
lb. per kw-hr. and at a cost of
approximately \$2 per ton for
energy, and with first cost of
equipment about \$8 per lb. of
metal heated per hr.

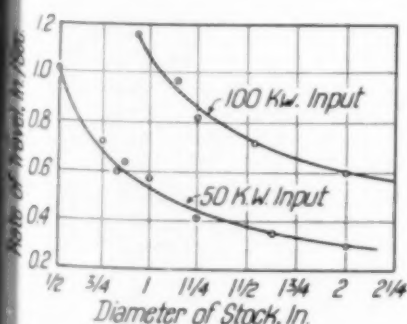


Fig. 3a — Approximate Rate of Travel of Stock for Continuous Surface Hardening of Various Diameters to Depths Associated With Frequencies Employed. Modifications are necessary depending upon the response of the metallurgical structure

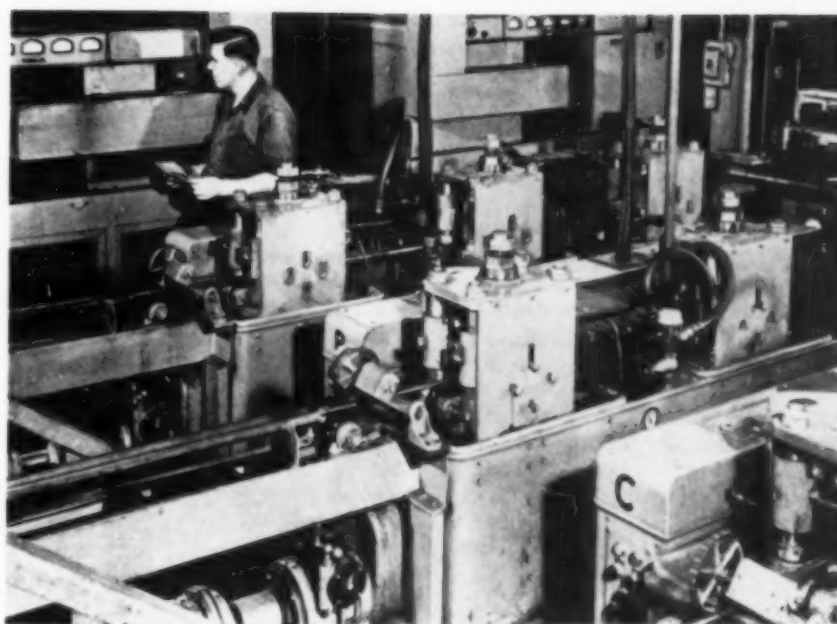


Fig. 2a — Progressive Surface Hardening Unit for Large Sections, Adjustable for Various Lengths of Shafts Such as Pump Rods and Piston Rods. It also has an automatic adjustment for processing specified areas. Adaptable for shaft lengths up to 6 ft. (or longer on special equipment) and in diameters up to 10 in.

Large Gears Surface Hardened

That the size of work being hardened in production is steadily going upward is proven by a notable article by Glen C. Riegel in *Metal Progress* for July 1943, showing how a final drive gear transmitting 113 hp. on a 17½-ton tractor is surface hardened. This spur gear is 25.7-in. pitch diameter, 5-in. face, cut with involute teeth of 0.514-in. chordal thickness. The teeth are crown shaved while soft and then hardened to C-50 0.130 in. deep at the pitch line without measurable change of form. Out-of-roundness of this 2-ft. gear after heat treatment averages no more than 0.007 in. at pitch diameter. The two-station hardening bench is served with an 800-hp. motor generating 9600-cycle current. Floor-to-floor time is about 4 min.

Saving in Alloying Metals

Aside from the large saving in the above mentioned gear job of machine shop costs (the old practice was to shave a hardened gear, whereas the new practice shaves the teeth while soft and holds them to size after hardening) is the production of a more serviceable gear of plain carbon steel

rather than alloy. Proper hardness and strength is now had from S.A.E. 1045 steel, whereas the old practice used a 3½% nickel steel (S.A.E. 2345). Each gear saves 13 lb. of nickel, and this was of prime importance to the armament program, to say nothing of the saving in dollars and cents.

Other instances of changeover from alloy to plain carbon steel, or from a higher alloy to a lower alloy steel are numerous. Space permits only a casual mention of changes in crankshafts made by Ohio Crankshaft Co. and other large firms.

Crankshafts, which had formerly been heat treated to approximately 300 Brinell, represented a compromise between wear

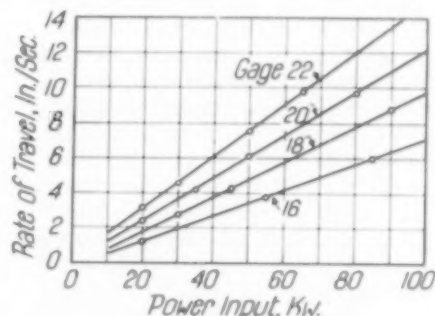


Fig. 4a — Rate of Travel Versus Power Input for Continuous Heating of Tubing to 1600° F. for Normalizing or Hardening

resistance and machinability. They were made of alloy steels but not because of the higher core properties attained. Substitution of plain carbon steel results in such economies in mass production that the cost of the induction heating equipment is recovered in a time as short as six months.

For example, a 100-lb. diesel engine shaft of S.A.E. 3140, heat treated and machined, costs approximately \$50, whereas the same shaft made from a normalized S.A.E. 1045 forging and induction hardened may run but \$35 and will outwear the alloy shaft by hundreds of thousands of miles.

Temperature Control

It is worthy of emphasis, time after time, that fullest advantage of the skin effect of high frequency heat is obtained only if the surface can be brought up to hardening temperature *in a few seconds*. Thus we must introduce a sufficient amount of energy into the inductor to generate adequate currents in the surface of the zone to be heated. Since holding fixtures will accurately place the piece inside the inductor block in its correct position, and since the flow of current can be *very* closely controlled automatically, the *time* required to produce the desired surface hardening need only be duplicated in order to duplicate satisfactory hardened surfaces, piece by piece. Time, rather than temperature, is the main control, and this is very easily set by electric timers.

Obviously, metallurgical examination and hardness survey must determine what adjustments, if any, are necessary when a new heat of steel arrives. The prior metallic structure affects the final result due to differences in rate of solution of the microconstituents. This is especially true of the complex carbides existing in alloy steels containing considerable chromium or molybdenum. However, solution and diffusion of plain iron carbide (cementite) into austenite above the critical temperature, is *exceedingly* rapid, measured indeed by a fraction of a second.

Coarse grain is another thing which the metallurgist watches, and here again rapid induction heating is of advantage. Grain

growth requires time, and due to the short heating times, a considerable latitude in degree of temperature is permissible without causing noticeable coarsening of the structure (grain growth).

In a few installations, auxiliary temperature control (other than by regulation of power input and heating time) is effected by thermocouples and radiation pyrometers of various types. For example, in heating shells for forming or forging, or in a reheating set-up where the temperature of the shell at the time it is placed

in the induction heater varies considerably from piece to piece, we are unable to set automatic controls for heating to a specified temperature since the introduction of a fixed amount of energy for a specified amount of time produces a uniform product only if the heat content of the material at the start is the same each time. Radiation pyrometers can then be used which are connected through the control circuit and automatically turn off the power when the correct temperature is reached.

Frequencies From 100,000 to 500,000

(Cont. from p. 807) above the critical, as for hardening applications, for above this point the magnetic properties disappear. It is therefore interesting to note that at 60 cycles the total heating effect is composed of 80% hysteresis and 20% eddy current losses (as in silicon steel transformer sheet); as the frequency rises, the ratio of eddy current losses to hysteresis increases sharply, so that at 125,000 cycles, eddy current and hysteresis losses are evenly proportioned, and as the frequency increases, eddy current losses tend to predominate at the more commonly used induction heating frequencies.

An experiment illustrating this phenomenon can easily be performed by anyone having access to a high frequency source. Using an ordinary round work coil of convenient size, and a piece of common steel strapping 12 in. long, the piece is first held perpendicular to the plane of the coil (as shown in plan in Fig. 1b). In this position the test piece presents a minimum surface for eddy

current losses, and practically all the heating effect is the result of hysteresis losses. The maximum temperature that can be achieved runs to about 1400° F., even though the strip be held indefinitely in this position.

However, if the position of the piece is now changed (Fig. 2b) so that the entire flat surface of the strip is presented as a target for the eddy currents, it will come up to the melting temperature very rapidly. It can thus be seen that a higher ratio of eddy current to hysteresis losses, as encountered in the 100,000 to 500,000-cycle range, can be extremely advantageous in steel hardening, and in the heating of non-ferrous materials where hysteresis losses are not utilized at all.

No one contests the fact that the heating effects on irregular surfaces are very noticeably affected by the frequency of the induced current; the higher the

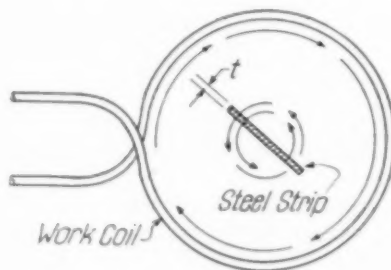


Fig. 1b — If a Piece of 1-In. Steel Strapping, 12 In. Long, Is Held Vertically in an Inductor Coil Carrying High Frequency Current, It Cannot Be Heated Higher Than About 1400°F.

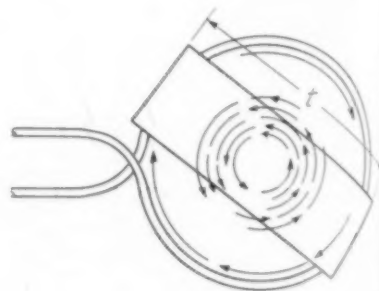


Fig. 2b — If the Piece of Fig. 1b Is Laid Flat, Just Above the Coil, It Is Heated to Melting Very Rapidly. In both positions the heating from eddy currents (independent of the magnetic conditions of the piece) is proportional to the thickness of the piece when held in the plane of the coil.

frequency, the more closely the outside surface is hugged. When sufficient power is applied to keep the time element at a minimum, the intermediate zone between hardened and adjacent unhardened zones is also of vanishing thickness. Frequently the mass of underlying unheated metal can be used to self-quench the part. Of course, under these conditions, the intermediate zone would not be as sharply limited as though the part were to be quenched by conventional means.

An illustration of such possibilities is the differential hardening of an airplane starter clutch. The entire part was furnace hardened and oil quenched to C-45 to develop core properties. It was then desired to harden some teeth to C-55 without annealing the adjoining section, and the part was therefore immersed in an oil bath to the point at which the additional hardness was desired. The teeth were then heated by induction, at a frequency of approximately 400,000 cycles for 3 sec.; as soon as the hardening temperature was reached, the operator tipped the part into the oil bath for immediate quenching.

In this job excellent results were obtained with practically no annealed section. Some necessary precautions must be taken where hardness gradients are high, especially in highly stressed parts, and this subject was very capably discussed by J. O. Almen, in *Metal Progress* for December 1944, under the title "Some Needed Precautions When Induction and Flame Hardening".

Work Coils

Work coils for the 100,000 to 500,000-cycle range are considerably simpler than they are at the lower frequencies. Usually they can be simply fashioned of copper tubing to follow the general contour of the work; since the coupling or spacing of the work to the coil is not excessively critical, precision machining of coils and auxiliary locating devices may usually be avoided. The results to be attained govern the degree of coupling to the work at the higher frequencies. In general, the closer the coupling, the shallower the depth of penetration; the looser the coupling, the

deeper the penetration. (Penetration of heat takes place by conduction from one layer of metal to the next underlying layer.) It is necessary to adjust power and time controls to prevent burning of the outer layers when equipment is used in this fashion for deep heating. Exact depth of penetration, from a thin case to through-hardening, may be achieved when the job is properly handled.

The foregoing remarks apply to all equipment built to operate in the 100,000 to 500,000-cycle range. Two types of equipment are commonly utilized to generate power at these frequencies—the vacuum-tube oscillator and the spark-gap converter. Most of the tube units are built to operate at a fixed frequency, usually above

sufficient voltage to discharge across a set of spark gaps of predetermined settings. The condenser then recharges, and once more discharges across the gaps, and the sequence is repeated thousands of times per second, thus forming an oscillatory circuit. A load circuit, comprising a load coil, load, and associated tank condensers, is connected across the oscillatory circuit. The load circuit will operate most efficiently at the so-called "optimum frequency", which is determined by the values of its components. To generate optimum frequency, the oscillatory circuit is tuned by varying the tunable inductances so that the frequency of both circuits is exactly the same—or, as it is termed, "in resonance". Maximum current then flows through

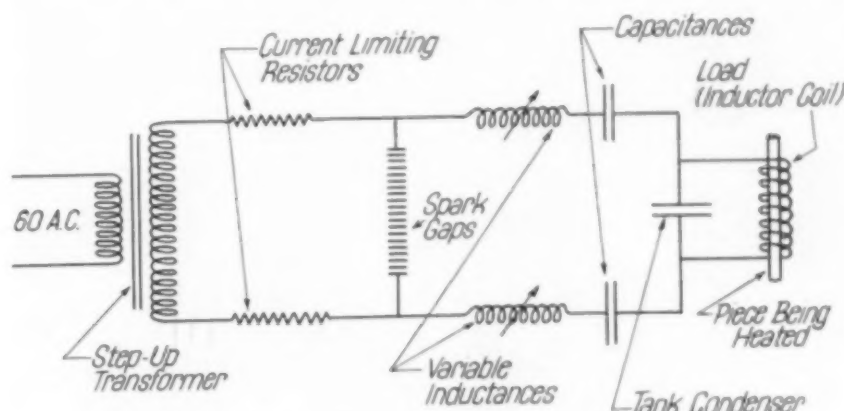


Fig. 3b — Basic Circuit Diagram for Generating High Frequency Current by Means of Spark-Gap Converter

300,000 cycles, due to the fact that a frequency-changing device, or tuning mechanism, is expensive to build and maintain. Commercial equipment utilizing the spark-gap converter, on the other hand, usually incorporates a means to vary the frequency, as determined by the work and load coil, and operates as required by these conditions in the band from 125,000 to 450,000 cycles. Since this latter type is the most widely used source of power of these frequencies, a brief description will be of interest.

Basic Circuit

The spark-gap converter is essentially a step-up transformer which, operated in conjunction with a tunable inductance and a fixed capacitance, charges the capacitance (or condenser) to a

the load coil, and thus into the work. This basic circuit diagram is shown in Fig. 3b. Incidentally, with this arrangement, the voltage at the load coil in resonance is usually low, depending on its size and number of turns. The circuit is completely balanced, with the center of the coil at zero potential, and complete safety to the operator of the equipment is thereby assured.

The main components, simple and rugged, can be placed in a compact unit. Spark gaps and condensers are specially built with liberal safety factors. Water-cooled spark gaps with tungsten firing surfaces 0.100 in. thick have a normal life expectancy of 15,000 hr. of operation. The only maintenance required is checking the gap openings with a feeler gage every 50 hr. and adjusting them with a wrench, if

required, to compensate for the evaporation of tungsten.

The outstanding advantage of a variable frequency range is its extraordinary adaptability to a wide range of heating applications (including melting, which is an application for which tube units are not recommended). Any size of coil, ranging from $\frac{1}{8}$ to 48 in. in diameter, can be connected directly to the output terminals, and the unit then tuned to maximum efficiency for the particular job on hand at the moment, by turning a single knob. The operation is similar to that which

reached the Curie magnetic point can be compensated for in advance. Practically the same coil current can be maintained both before and after the part has reached the critical temperature; this results in shorter time cycles, lower energy requirements, and sharper definition to conductively heated areas.

Figure 4b shows a typical installation for hardening drill bushings, where the hardened area is to be closely controlled. The unit has a special quench table, containing a fixture which rotates the work during the heat-

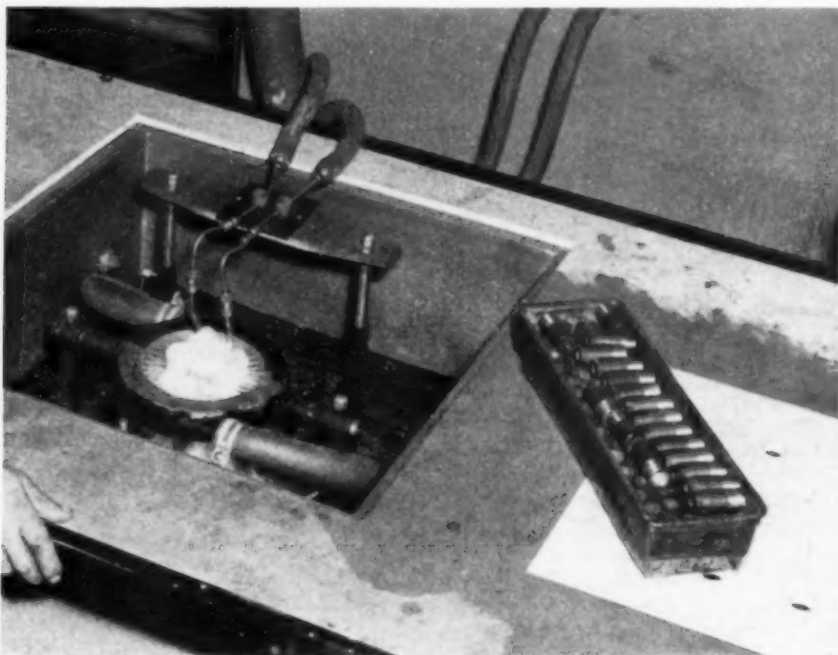


Fig. 4b—Hardening Drill Bushings to Close Limits; Bushing Is Rotated Within Heating Coil. (Courtesy Acme Industrial Co.)

occurs when tuning a radio to a particular station—in this case the work representing the radio station and the machine representing the radio. The knob is rotated until a maximum reading is obtained on an indicating meter, and at this point the optimum resonance condition prevails in the circuit.

Energy Control

Another advantage of a tunable high frequency source is that it can assure maximum energy transfer from the converter to the load under all conditions. This is of especial interest in heating for hardening, for the de-tuning effect that occurs when the steel has

ing cycle and times the quench. Also included in the quench table are water cooled tanks for both brine and oil quenching.

Self-contained units can be easily moved from one location to another in the plant. This factor has been largely instrumental in limiting the size of spark-gap units; the largest available at present has 30-kw. input. Two or more units are readily hooked up to operate simultaneously, and thus large work can be handled on which there is limited production. On many jobs, ingenious progressive feed arrangements are being utilized to process work which would normally require electrical equipment many times the 30-kw. size.



Fig. 5b—Fixture for Heating and Oil Quenching the Teeth of a Herringbone Gear, Tooth by Tooth. Heating is done, not by the round coil, but by a conforming loop that extends toward the left, just under the steel plate. Oil spray pipes are above the plate. (Courtesy Lindberg Steel Treating Co.)

For example, Fig. 5b shows an interesting set-up for hardening the teeth of a herringbone gear. Steel is NE9445, and the teeth and clutch segments are to be hardened to C-56 without runout. As no hardness is desired at the root of the teeth, it becomes practical to do this job on a 30-kw. unit, tooth by tooth. The hardened area is well defined in the view. The gear is indexed tooth by tooth, heated, and oil quenched. One precaution with oil spray quenching is to make certain that sufficient oil is delivered to flood the part completely; otherwise the oil will flash. Gears as large as 24 in. diameter, with 5-in. face, have been similarly and successfully processed in this plant with the same equipment.

A discussion of the merits of induction heating would be incomplete without the observation that the field of application has scarcely been scratched, and that as its possibilities are more widely appreciated, great strides will be made in its use by industry as time goes by.

Tube Units

(Continued from page 807)

In discussing this effect one should note the utility of going to frequencies above 375,000 cycles to gain further shallowness of hardness pattern. If the curves of penetration versus frequency are extrapolated to 1,000,000 cycles, we see that the minimum theoretical value reduces to 0.0025 in. and the practical value to 0.013 in. (Point E), so that the hardened thickness is reduced only from 0.015 to 0.013 in., a matter of 0.002 in., which in practice is of no advantage. On top of this, the cost of equipment goes up as the higher frequencies are generated, and consequently it is advantageous to stay down in the range of 375,000 cycles in order to avoid this large increase in equipment cost. Much of the discussion about heating with 1,000,000 cycles has been by manufacturers with experience in radio broadcasting, with oscillators already designed to produce this frequency.

The second attribute of the higher frequencies is the ability to heat small diameters and thin sections. The energy transferred, with all other values remaining constant, varies as the square root of the frequency when we are dealing with currents above 10,000 cycles. Consequently for given limitations of spacing and ampere-turns, increased energy can be transferred as the frequency is increased. In parts of small diameters and thin sheets the ratio of surface area to mass is large, and consequently much of the energy goes off as radiation and does not show itself as a temperature rise in the work. As can readily be deduced from the curves of Fig. 2c, which plot the well-known radiation relationship depending on the difference of the fourth powers of the absolute temperatures of radiating and receiving bodies, the lower frequencies meet a stalemate where they are heated throughout, saturated at a lower temperature than required. With the use of 375,000 cycle energy, steel stock of diameters as small as 0.009 in. has been successfully brought up to hardening temperature, and sheet stock having a thickness of 0.005 in. has also been successfully heat treated. Naturally, wherever this type of

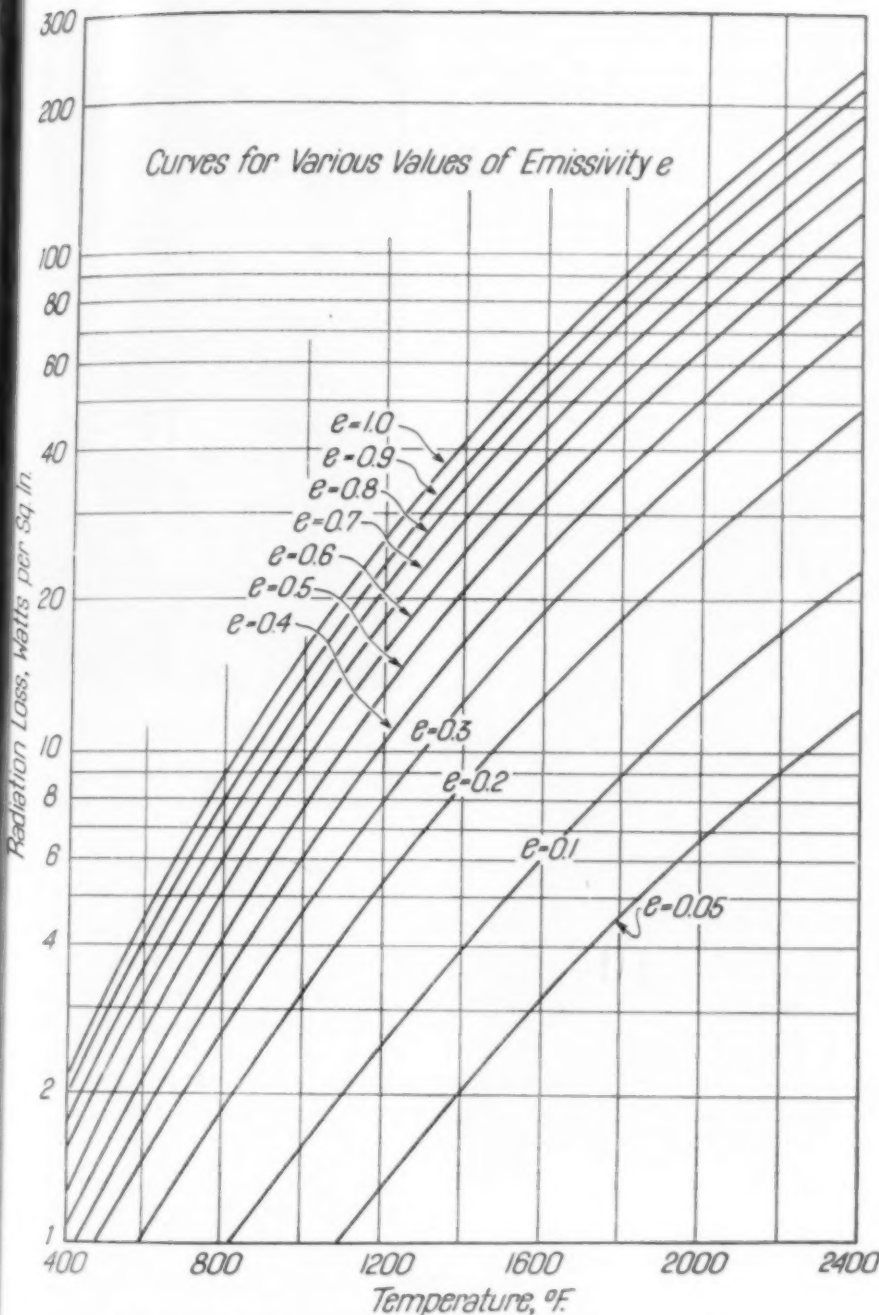


Fig. 2c — Family of Curves Showing Radiation Losses, in Watts per Sq. In., From Metal Surfaces at Various Temperatures (°F.). Emission of heat depends on the character of the surface — that is, its "emissivity" — and approximate values of this factor e are given in the table below. The formula is

$$W_r = 37 e \left[\left(\frac{T_1}{1000} \right)^4 - \left(\frac{T_2}{1000} \right)^4 \right]$$

Typical Values of e

MATERIAL	POLISHED	ROUGH	OXIDIZED
Aluminum	0.04	0.055	0.11/0.19
Brass	0.03	0.06/0.20	0.60
Copper	0.02		0.57
Steel	0.13/0.40		0.80/0.95
Nickel	0.05		0.40
Silver	0.035		

material is heated, the proportion of radiation loss is high and often makes the over-all process unfeasible economically.

These words should not be construed to mean that surface hardening at these small diameters can be achieved by high frequency energy. In our laboratory we have surface hardened S.A.E. 1045 steel 0.125 in. in diameter to a depth of about 0.020 in., but this is not altogether practical, and I doubt very much if it would find an application in the metallurgical field. Thermal conduction, causing the heat energy to flow to the inner part, brings about practically through-heating on such small diameter stock or thin sheet.

The third and last reason why higher frequencies have an advantage over lower frequencies is their ability to transfer energy over greater distances between the coil carrying the electrical currents and the metal being heated. The basic reason for this is that as we increase the coupling distance between work coil and the work to be heated, the magnetic flux density falls off, and consequently we are subjecting the material to a lesser field density. This can be compensated for by increase in frequency, so that for a given amount of power put into the work we can have various products of frequency times coupling factor, other variables remaining constant. The physical

make-up of the various parts which require induction heating, and also the manner of handling in jigs and fixtures, often prevent close coupling, and it is then necessary to use distances as great as $\frac{1}{4}$ to $\frac{1}{2}$ in. between coil and work. In order to transfer the required amount of power, frequencies of the order of 375,000 cycles must be used. In this way the over-all picture becomes one which depends largely upon economy and convenience in handling the work, and if the low frequencies were all that were available,



Fig. 4c—Longitudinal Section Through Nozzle Made of Two Stampings of $\frac{3}{16}$ -In. Plate, S. A. E. 1010. Joint heated to 1950° F. by 375,000 cycles; welded at 4000 psi.

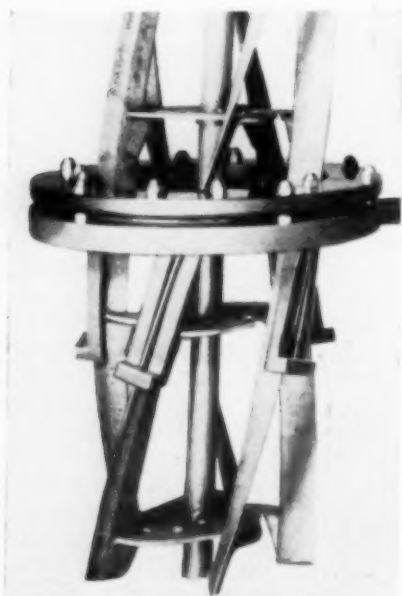


Fig. 3c—Heating Coil and Quenching Fixture for Simultaneous Hardening of Cutter Blades on a Lawn Mower Reel

the use of induction heating could not be considered.

It is well to mention at this time the matter of current or power density, kw. per sq.in. of surface being heated. This parameter is most important when the higher frequencies are used. Unless sufficient power is transferred per unit of surface so it is heated rapidly before the energy is thermally conducted into the piece or radiated outside, the localized effect of the higher frequency is entirely masked. Practical values of from 5 to 10 kw. per sq.in. will approximate the

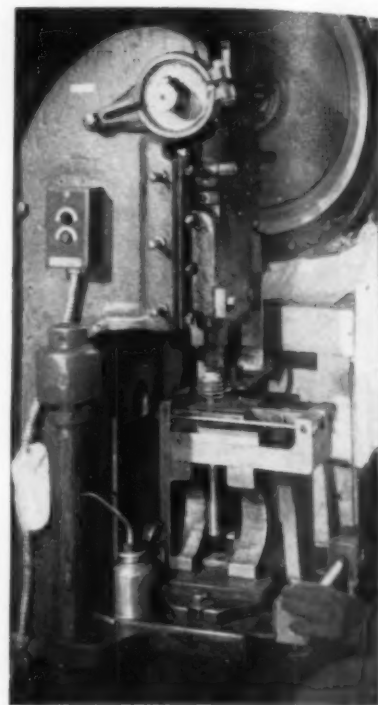


Fig. 5c—A High Frequency Coil Heats the End of a Thin Walled Tubing Prior to Expanding. Time cycle for heating is automatically coordinated with the press

hardened layers discussed above, while the extremely thin hardened layers will require as high as 15 to 20 kw. per sq.in. As soon as the power per unit area is reduced, the effect of the 375,000-cycle energy approximates very closely that of the 10,000-cycle energy, and there is little difference in heat pattern.

Some representative jobs of heating for hardening, for welding, and for shrinking are illustrated in Fig. 3c, 4c and 5c.

Now as to how the high frequency current is to be generated, that is a commercial rather than a metallurgical problem. In other words, 300,000-cycle current from a spark-gap circuit has precisely the same metallurgical effect as 300,000-cycle current from a vacuum tube circuit—other conditions being the same. The commercial arguments advanced by the firms promoting one or the other have little or no place in this discussion—they belong rather to the advertising pages since they refer principally to matters such as first cost, maintenance cost, portability, ruggedness, and so on. The extra cost of the equipment using vacuum tubes is warranted if the experience of

(Continued on page 832)

In Wartime — Salt Baths — In Peacetime

By W. W. Winters
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Further, electrodes may now be simply replaced, when necessary, in only 7 min.—thus avoiding solidification of the bath during the change and resulting in a minimum of down-time.

It is, therefore, now economically feasible to build salt bath furnaces of any size or shape, as well as to conveyerize the processing of work on a continuous basis. Many such installations are being used for hardening, carburizing, selective heating and isothermal heat treating, and their designs are adaptable to any production requirement regardless of size, shape or quantity of work.

One commonly used mechanized design is the "carrousel" unit, wherein work, suspended from fixtures, is rotated by a device located in the center of a circle which has three or more baths equally spaced around its periphery. Work automatically remains under treatment at each step throughout the cycle for consistently uniform periods of time, and then is returned for unloading, after complete processing, to the same point where it was loaded.

Another design, known as the "screw conveyor", comprises a motor-driven worm located directly over the salt bath which automatically moves suspended fixtures of work through the molten bath at a selected speed. Thus each piece of work remains under treatment for a definite time, selected for best results.

Perhaps the most flexible or adaptable means for mechanizing a series of heat treating operations, involving a battery of salt bath furnaces probably followed by wash-rinse and drying, is provided by the "jack rabbit" design. Here, the work is removed automatically from one bath and transferred to the next, returning either to the loading end or to an unloading station at the far end of a straight line processing route.

✓ Still another design accommodates small work suitable for basket handling. A number of baskets, each loaded with work, are rotated through the molten bath at a constant but adjustable speed. As each basket completes its cycle, it is automatically removed and the work discharged directly into an adjacent quench—the basket then returns where it may be automatically reloaded and placed into the bath to start the next heat treating cycle.

THE expanding uses of salt bath heat treatments during the last five years have not been afforded their present commercial acceptance without accompanying technological advancements in both bath and equipment. These developments are largely, if not entirely, applicable to the immersed-electrode principle for heating molten baths—which in itself comprises the greatest single advancement for the extension of numerous inherent advantages of heat treating metals by immersion in liquid baths.

A noteworthy improvement in furnace design has been the utilization of suitable refractory pots for many heat treatments previously carried out in metallic alloy pots. Ceramic containers have directly lengthened pot life in high speed steel tool hardening installations (2200 to 2400° F.) from the three to six months' service previously rendered by alloy pots, to the two to four years' operation now established as normal. Applied also to neutral hardening baths, which operate within the temperature range of 1500 to 1750° F., refractory pots remain in service four years and longer, in contrast to the previous life of one to two years for alloy pots. Use of ceramic materials also removed size limitations which were imposed on metal pot construction, as evidenced by the many salt baths now in service which measure 20 ft. and longer.

Improvements in electrode design and development of better alloys have also drastically reduced maintenance costs. Life of electrodes used in high speed steel hardening baths has been lengthened by 400%, to cite only one example.

Such techniques for continuous processing have in all instances boosted heat treating production while reducing manual labor. Elimination of errors plus maximum uniformity of results have established the economy of conveyerized baths. Indeed, their successful use on numerous war items has already aroused the interest of many mass production industries for applications in making better peacetime products at lower cost.

Neutral hardening of carbon and alloy steels in liquid baths (free of cyanide) was, even prior to the war, a widely used practice for heat treating without scale or decarburization. However, the adoption of the national emergency (NE)

significant heat treating advancement for peacetime industrial application. Definitely proven superior to conventional quench and temper methods for many, many machine parts, isothermal heat treatments have drastically lessened distortion (sometimes actually less than that obtained by oil quenching on a die-press machine) and improved physical properties on a multitude of products, such as bearings, aircraft engine parts, gears, springs, crankshafts, sewing and business machine parts, cutlery—even logging tools. In fact, many metal products which previously required costly finish grinding, due to excessive warp under heat treatment, can now be finish

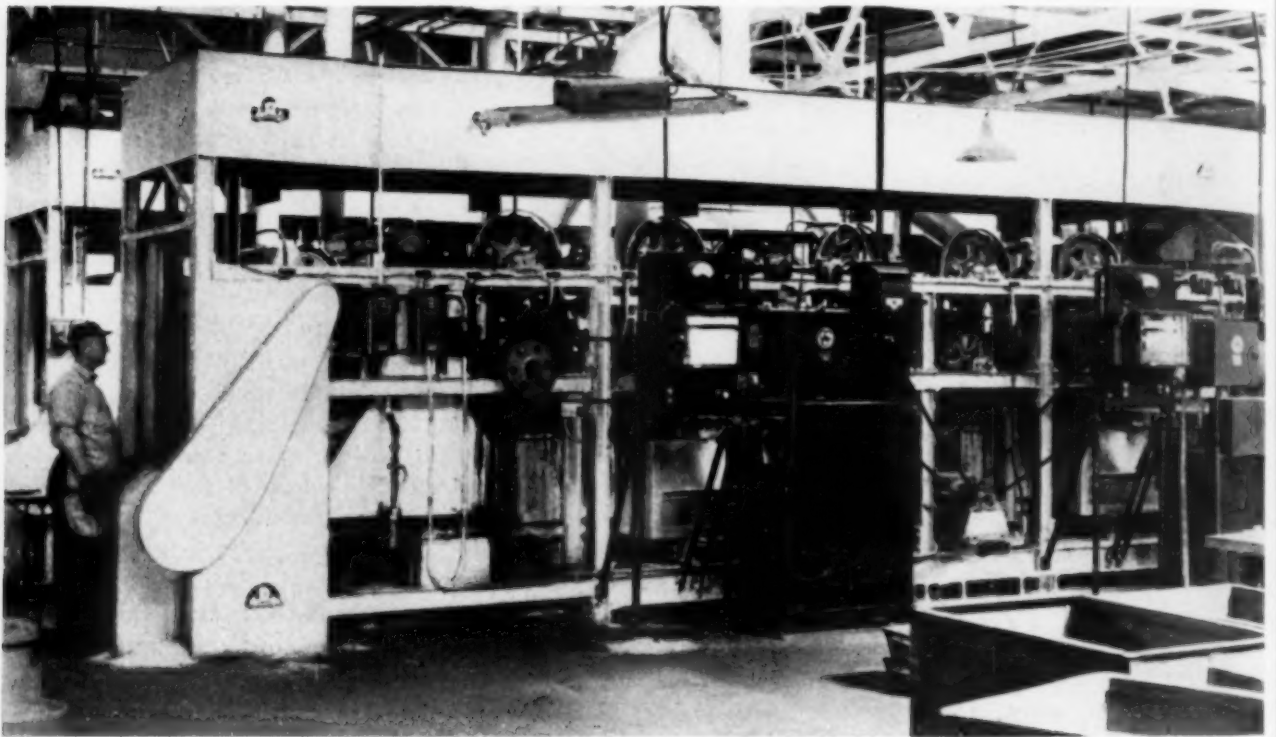


Fig. 1 — A Mechanized "Jack Rabbit" Design for Completely Processing Work Through a Series of Salt Bath Furnaces

steels as a conservation measure expanded the use of salt baths for hardening, since the narrower hardening ranges of NE steels required closer control of temperature and time. As a further development of neutral hardening treatments, wherein steels with constituents in a stable solution are quenched into oil, brine or water, investigations led to applying a hot salt quench in accordance with data procured from time-temperature-transformation or TTT-curves.

The consequent commercial development of these salt bath processes, now termed variously "isothermal quenching", "austempering", "martempering", "cyclic annealing", "hot quenching" and "interrupted quenching", is perhaps the most

machined prior to this isothermal processing and substantial savings have thus been effected.

Salt bath brazing was, only a few years ago, most generally applied to brazing copper alloys with silver solders. Today the process is advantageously applied to a host of ferrous and non-ferrous products. Aluminum assemblies for heat exchangers and coolers in aircraft, air conditioning and refrigeration systems are now salt bath brazed with startling production and economic advantages. In yet another typical installation, automotive-type starter assemblies are carburized and brazed in one operation, using a single salt bath. As a low cost method for producing intricate assemblies, which by other methods would

entail expensive machining operations, salt bath brazing has been well established during the war as a superior technique.

Liquid carburizing, previously limited to approximately 0.040-in. cases, is now being used for producing case depths up to 0.150 in. A few of the many products so carburized are steel rolls, armor plate, gears, crankshafts. Many war plants used one particular feature of salt bath carburizing to enormous advantage. Several different parts could be carburized, each to varying but controllable case depths, by simultaneous immersion in only one liquid bath. This adaptability,

tures from 1250 to 1400° F., was given an impetus.

The needs of aircraft production led to the construction of the largest immersed-electrode salt baths ever built, some with baths of 85 tons. Employed for the solution heat treatment of aluminum alloys and other age-hardenable metals (alclad, duralumin, copper-beryllium, and other non-ferrous alloys), salt baths are in operation in practically every aircraft plant for processing sheets, large structures up to 25 ft. long, stampings, fastenings and pressed shapes.

Wartime tungsten shortages increased the use of molybdenum high speed toolsteels. This alloy



Fig. 2 — Typical Large Nitrate Salt Bath Furnace, Installed in an Aircraft Plant for Solution Heat Treatment of Aluminum Alloy Parts

plus faster cycles, more uniform case depths, and better core structure resulting from salt bath carburizing, indicate increasing use of the process postwar.

Another new development, dependent upon the use of refractory pots, was the application of salt baths for annealing stainless steels at temperatures between 1650 and 2000° F. Here, the inherently faster heating rate of salt baths coupled with their characteristic avoidance of scale formation, established new records for high production and low annealing costs for all kinds of stainless, including wire, rod, castings, weldments, tubes, shapes and forgings. Also the use of salt baths for annealing high and low carbon steels, at tempera-

emphasized more than ever the essential need for salt bath heat treating, since the salt bath method was ideal for hardening the molybdenum high speeds without danger of decarburization or other surface changes. More high speed tools are treated by salt baths than by any other method.

In the intensified developments of liquid salt bath heat treatments for war production, metallurgists, chemists and engineers on the staffs of manufacturers of salts and furnaces have gained wholehearted acknowledgment from the entire metal industry. Reasonably, the great number of installations, plus results obtained, are indicative of continued expansion of salt baths in the immediate years ahead.

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Heat Treating Diagrams — S or TTT-Curves

INTELLIGENT use of S or TTT-curves for steel enables a fairly accurate prediction for designing a heat treatment to meet any normal requirements. Treatments which can be established if a curve of the steel or of a similar analysis is available are spheroidizing, normalizing, annealing, hardening, martempering and austempering. As is undoubtedly well known, the name S-curve was given to the isothermal transformation diagram because of the contour of the first diagrams studied; later TTT-curve (for time-temperature-transformation) was proposed and is perhaps a better name, for many of the diagrams have little similarity to an S.

Isothermal transformation curves for some 190 analyses are available, although they are scattered over a good number of publications, and some of them are not completely mapped. Recently a compilation of analyses was made giving the easiest available literature reference to these S-curves. The Editor of *Metal Progress* suggested the inclusion of data by which the metallurgist or heat treater, to whom the references were not available, could draw his own diagram with reasonable accuracy, and thus put at his disposal the knowledge of the transformation characteristics of various types of steels. This task was undertaken with the hope that efficient heat treatment would be promoted, as well as that a more intimate knowledge would result as to the behavior of steels of different chemical composition, grain size, and other common characteristics. For the student, selected

references giving data and discussion are listed on page 820 on a dozen related topics.

The practical heat treater must realize that the curves he will draw correspond to *isothermal* quenching—that is to say, quenching to a definite and constant temperature *above* the temperature of the usual oil, water or brine quench. This does not occur in practice except when a bath of lead, molten salt or hot oil is especially provided. Ordinary quenching into baths at room temperature does not result in isothermal (constant temperature) transformation, but in

transformations during continuous cooling. The latter start at temperatures and times which are displaced considerably below and to the right of the isothermal curves. A simple relationship has been established (see reference 4d), and the details and actual curves have been published for S.A.E. 6135, X4130 (reference 5b), S.A.E. 4340 (reference 21) NE8949, S.A.E. 3312 and "Extra" toolsteel (reference 4a). Because of the simple relationship between transformation during continuous cooling and transformation at constant subcritical temperature (below A_{c1}) one can establish, from the TTT-curve of a steel, such things as the rate of cooling necessary in a continuous cooling annealing operation to produce the desired structure (and hardness), and the temperature at which it is safe to remove the steel from the furnace and finish cooling to room temperature at a rapid rate.

The form of each of the curves constituting the diagram and their position with respect to the time axis is dependent on the rate at which austenite decomposes at constant subcritical temperatures. This transformation rate may be influenced by the following:

- | A. Direct Factors | B. Indirect Factors |
|-------------------------|--|
| 1. Rate of nucleation | 1. Chemical composition |
| 2. Rate of grain growth | 2. Degree of heterogeneity |
| | 3. Austenite grain size |
| | 4. Undissolved carbides and inclusions |

Certain alloying elements, or combination of alloying elements, change the form of the curve

in a characteristic way. This permits one to classify steels on the basis of the type of curve (references 22, 4a). The transformation of austenite to martensite is always *very* fast. The transformation of austenite to pearlite may be anything from very fast to very slow; usually it is very slow at temperatures just under A_{c1} . The intermediate transformation to an acicular structure commonly called bainite may be from very fast to non-existent; it may overlap either the pearlitic or the martensitic transformation, or be separated from them by a temperature range.

In practical martempering (reference 26) a temperature of 350 to 400° F. is recommended for the quench bath. However, the actual start of the martensitic reaction is above this for some steels, and for them the quench bath should obviously be higher. The actual M_s point is given in the tabulations, and it may be approximated by calculation when knowing the chemical analysis and using one of the formulas recommended for steels containing up to 0.80% C (references 4d and 23).

The index which follows lists the iron alloys for which S-curves have been published. They are arranged consecutively according to A.I.S.I. and S.A.E. numbering systems. The chemical analysis is given for each item or steel studied and a good reference. The *type* to which the curve has been assigned, because of its physical appearance, completes the index.

The physical appearance of the curves was adopted for the present index in preference to any theoretical classification to simplify the data sheets for each type and to facilitate drawing the curves. To permit visualization of what changes may be expected between the curves representing "start" S and "finish" F of the transformation, four groups were assigned to Types I, II, and III, and three groups to Type IV. All readily available S-curves were assigned to five types.

To draw the curve for a certain steel—for example, A.I.S.I. C1080, turn to the index, page 821, which shows that steel to be Item 16 and belong to Type I. In the data sheet for Type I (page 824), a sketch shows the general contour of the S-curves and the location of the various S and F points. Seventeen steels are listed in this group, of which Item 16 is the second. (Data on the austenitizing temperature and the grain size are given where available.) On any convenient sheet of semi-logarithmic coordinate paper the A_{c1} temperature for this steel (1340° F.) should be drawn as a horizontal. Then proceed to locate Point S_1 by obtaining the inter-

Topical References

Selected reading, for a discussion of several important topics, would be:

I. Effect of important factors on S-curves	
1. Analysis	Reference
a Carbon	3d, 3a
b Individual alloying elements	12, 3d, 3a, 1a to 1e
c Several alloying elements	3d, 3a, 1a to 1e
2. Homogenization	3d
3. Segregation and banding	3d
4. Austenitizing temperature	3d, 3a
5. Grain size	3d, 3g
6. Effect of carburizing	3a
7. Effect of rolling on ingot steel	2
8. Overheating, as on welding	10
II. Continuous cooling curves	4a, 5b, 14, 21
III. Cast iron and malleable iron	17, 18, 19, 24
IV. M_s points of steels	4d, 23
V. Isothermal heat treating practice	4d, 25, 26, 27, 28 & many others.

section of lines drawn perpendicular to the corresponding temperature and time coordinates. After locating all the S points a smooth curve should be drawn through them, ending approximately at the M_s temperature. Locate the F points for the finish of transformation in a similar way and draw a smooth curve through them. The hardness data can be indicated close to the corresponding F points or on the right margin of the paper. Hardness—or microstructure—at the end of transformation is of interest to the heat treater when planning a cycle.

To make the tables brief and keep them within practical bounds several abbreviations had to be adopted. To summarize: Two columns apply to each *start* point—first, the temperature in °F., and then the time. (Abbreviations for time should be self explanatory; s corresponds to seconds, m minutes, hr hour, and d day.) For the *finish* of the transformation, three columns are given for each F point. The first column gives the temperature, the second the time, the third the hardness as expressed in the original work. Abbreviations for hardness are: B correspond to Brinell, C to Rockwell C scale, and V to Vickers.

For each type of curve in the data sheets, the first column lists the cross reference or *item* to the index, from which the analysis is obtained.

A letter *a*, *b*, *c* or *d* may indicate that the particular steel has been studied at more than one austenitizing temperature. An occasional α serves to introduce a steel which had not been included when the first compilation was made.

The second column in the data sheets gives the austenitizing temperature. A \dagger after the temperature means that the austenite may contain undissolved carbides, and that the area above and to the left of the curve representing start of transformation is not uniform austenite by any means but contains austenite and precipitated carbides. (Such steels start their transformation much more quickly than steels with homogeneous austenite.)

The other columns have already been described.

For some curves data on only the beginning of the transformation were available; for others data for only a 50% completed transformation. The former is apparent; and the latter indicated.

Bibliography

- 1a—J. A. Blanchard, R. M. Parke and A. J. Herzig, "The Effect of Molybdenum on the Isothermal Subcritical Transformation of Austenite in Eutectoid and Hyper-Eutectoid Steels," *Am. Soc. Metals Trans.*, 1943, p. 849.
- 1b—J. L. Ham, R. M. Parke and A. J. Herzig, "Kinetics and Reaction Products of the Isothermal Transformation of 26 Per Cent Tungsten-6 Per Cent Molybdenum High Speed Steel," *Am. Soc. Metals Trans.*, 1941, p. 623.
- 1c—J. R. Blanchard, R. M. Parke and A. J. Herzig, "The Effect of Molybdenum on the Isothermal Subcritical Transformation of Austenite in Low and Medium Carbon Steels," *Am. Soc. Metals Trans.*, Vol. 29, 1941, p. 317.
- 1d—R. M. Parke and A. J. Herzig, "Hardenability of Molybdenum S.A.E. Steels," *Metals and Alloys*, Vol. 11, 1940, p. 6.
- 1e—Climax Molybdenum Co., N. Y., "Molybdenum—Fundamental Effects in Steel" (1939), 16 pages.
- 2—C. J. Eddy, R. J. Marcotte and R. J. Smith, "Time-Temperature Curves for Use in the Heat Treatment of Cast Steel," *Am. Inst. Mining Met. Engrs., Tech. Pub. No. 1846*, 1945, 18 pages.
- 3a—United States Steel Corp., "Atlas of Isothermal Transformation Diagrams," Pittsburgh, 1943.
- 3b—E. C. Bain, "Functions of the Alloying Elements in Steel," *American Society for Metals*, Cleveland, 1939, 312 pages.
- 3c—M. A. Grossmann, "Principles of Heat Treatment," *American Society for Metals*, Cleveland, 1935, 147 pages.
- 3d—E. S. Davenport, "Isothermal Transformation in Steel," *Am. Soc. Metals Trans.*, Vol. 27, 1939, p. 837.
- 3e—J. G. Zimmerman, R. H. Aborn and E. C. Bain, "Some Effects of Small Additions of Vanadium to Eutectoid Steel," *Am. Soc. Metals Trans.*, 1937, p. 755.
- 3f—R. J. Rickett, J. G. Cutton, C. B. Bernhart, Jr., and J. R. Millikin, "Isothermal Transformation and End-Quench Hardenability of Some NE Steels," *Am. Soc. Metals Trans.*, Vol. 35, 1945, p. 22.
- 3g—E. S. Davenport, R. A. Grange and R. J. Hafsten, "Influence of Austenite Grain Size Upon Isothermal Transformation Behavior of S.A.E. 4140 Steel," *Am. Inst. Mining Met. Engrs. Trans.*, Vol. 145, 1941, p. 301.
- 3h—E. C. Bain and E. S. Davenport, "Transformation of Austenite at Constant Sub-Critical Temperatures," *Am. Inst. Mining Met. Engrs. Trans. Iron Steel Div.*, Vol. 90, 1930, p. 117.
- 4—P. Payson, "Tool Steels," *Crucible Steel Co. of America*, New York, Nov. 1944.
- 4a—P. Payson, "The Annealing of Steel," *Iron Age*, Vol. 151, 1943, June 24, p. 44, 130, Vol. 152, 1943, July 1, p. 48; July 8, p. 74; July 15, p. 70; July 22, p. 60.
- 4b—P. Payson and J. L. Klein, "The Hardening of Tool Steels," *Am. Soc. Metals Trans.*, Vol. 31, 1943, p. 218.
- 4c—P. Payson, W. L. Hodapp and J. Leeder, "The Spheroidizing of Steel by Isothermal Transformation," *Am. Soc. Metals Trans.*, Vol. 28, 1940, p. 306.
- 4d—Peter Payson and Charles H. Savage, "Martensite Reactions in Alloy Steels," *Am. Soc. Metals Trans.*, Vol. 33, 1944, p. 261; Louis A. Carapella, "Computing A" or Ms (Transformation Temperature on Quenching) From Analysis," *Metal Progress*, July 1944, p. 108.
- 5a—*Metal Progress*, Collection of Data Sheets, Cleveland, 1943.
- 5b—C. A. Liedholm, "Continuous Cooling Transformation Diagram, From Modified End-Quench Method," *Metal Progress*, Vol. 45, Jan. 1944, p. 94; "Transformation of S.A.E. 4330 During Continuous Cooling," June 1944, p. 1110-B; "Transformation of NE8630 During Continuous Cooling," Vol. 46, Sept. 1944, p. 946-B.
- 6—Charles R. Wilks, Earnshaw Cook and Howard S. Avery, "Further Developments of the End Quench Hardenability Test," *Am. Soc. Metals Trans.*, 1945, p. 1.
- 7—R. A. Flinn, E. Cook and J. A. Fellows, "A Quantitative Study of Austenite Transformation," *Am. Soc. Metals Trans.*, Vol. 31, 1943, p. 41.
- 8a—"Isothermal Transformation Diagrams (S-Curves) for NE 8620 and 9420 Steels," *Nickel Steel Topics*, Vol. 14, No. 1, 1945, p. 4; No. 2, p. 7.
- 8b—International Nickel Company, "Isothermal Transformation Diagrams (S-Curves) for Some Constructional Alloy and Carbon Steels," *International Nickel Co. Development and Research Division*, New York, 1943, 29 pages.
- 9—B. M. Loring, "The S-Curve of a Chromium-Nickel Steel," *Am. Inst. Mining Met. Engrs. Trans.*, Vol. 150, 1942, p. 283.
- 10—K. Winterton, "The Effect of Overheating on the Transformation Characteristics of a Nickel-Chromium-Molybdenum Steel," *Iron Steel Inst. (London)*, *Advance Paper*, Nov. 1944, 7 pages.
- 11—A. Dubé and S. L. Gertsman, "Some Metallurgical Principles for the Efficient Heat Treatment of Steel," *Can. Inst. Mining Met. Trans.*, 1945, p. 165.
- 12—T. Lyman and A. R. Troiano, "Isothermal Transformation of Austenite in One Per Cent Carbon High-Chromium Steels," *Am. Inst. Mining Met. Engrs. Tech. Pub. No. 1801*, 1945.
- 13—N. L. Ziegler and W. L. Meinhart, Discussion of "The Influence of Alloying Elements on the Critical Points of Steels as Measured by the Dilatometer," by R. N. Gillmor, *Am. Soc. Metals Trans.*, Vol. 30, 1942, p. 1411.
- 14—A. H. Cottrell, "Tensile Properties of Unstable Austenite and Its Low-Temperature Decomposition Products," *Iron Steel Inst. (London)*, Preprint, Nov. 1944.
- 15—P. Gordon, M. Cohen and R. S. Rose, "The Kinetics of Austenite Transformation," *Am. Soc. Metals Trans.*, Vol. 31, 1943, p. 41.

(Continued on page 824)

Index of S-Curves or TTT-Curves For Typical Curves and Thermal Data See Pages 824 to 831

ITEM	SPECIFICATION OR KIND			CHEMICAL COMPOSITIONS IN PER CENT						REF.	PAGE	CURVE TYPE	ITEM
	A.I.S.I.	S.A.E.	OTHER	C	Mn	Si	Ni	Cr	Mo				
1	C1012			0.12	0.65	0.26	0.06		0.008	1c	319	1b	1
2	C1030	1030	NE1030, cast steel Rolled	0.30	0.75	0.46				2	24	1c	2
3				0.35	0.37					3a	18	1c	3
4				0.45	0.67	0.26			0.009	1c	321	1c	4
5		1050		0.46	0.80	0.19	0.17	0.13		4c, 4a	314, 32	1c	5
6	C1050	1050		0.50	0.91					3a	20	1a	6
7			WD1055, NE1054	0.54	0.46	0.20				3a	21	1c	7
8			50% transformation	0.55	0.50					3c	137	1c	8
9				0.59	0.30					3d	853	1b	9
10				0.65	0.39	0.19	0.19	0.16	0.03	1d	11	1b	10
11	C1064		NE1065	0.64	0.68	0.22				3a	40	1c	11
12	C1066	1060		0.63	0.87					3a	100	1c	12
		X-1065											
13			Boron modified	0.63	0.87					3a	101	1a	13
14			QQ-W474	0.64	1.13	0.09				3a	22	1a	14
15				0.78	0.36	0.16				5a	23	1	15
16	C1080	1080	NE1080, WD1080	0.79	0.76					3a	23	1	16
17			See Item 15	0.89						5a	23	1	17
18				0.85	0.23	0.18	0.05	0.07		4a	36	1	18
19	C1086	1095		0.89	0.29	0.15				3a	24	1	19
20			50% transformation	0.88	0.41	0.41				3c	771	1	20
20x		1095		0.95	0.45					3d	858	1	20x
21			Toolsteel	1.13	0.30	0.17				3a	25	1c	21
22			Toolsteel	1.14	0.22	0.16				4b	224	1b	22
23			Toolsteel, Navy	1.16	0.27	0.21	0.08	0.11		4a	37	1b	23
24				1.17	0.03	0.18		0.26		3h	133	1	24
25				1.17	0.30			0.26		3d	855	1	25
26				0.65	1.32					3d	853	1	26
27				0.26	1.51	0.42		0.45	0.30	6	10	IIIb	27
28				0.30	1.63	0.49		0.44	0.33	7	64	IIIa	28
29	A1335	T1335	Not homogenized	0.35	1.85	0.19				3a	19	II	29
29x		T1335	Homogenized							3d	871	1a	29x
30				0.47	2.10	0.01	0.04	0.06		16	114	1a	30
31				0.51	1.56	0.04	0.04	0.03		16	113	1a	31
32				0.65	1.1					3c	137	1a	32
33				0.55	3.9					3c	137	1a	33
34				0.53	4.05	0.01	0.04	0.04		16	115	III	34
35				0.60			0.50			3c	137	1b	35
36				0.61	0.26		0.94			3a	28	1c	36
37				0.57	0.24		1.94			3a	29	1c	37
38				0.55	0.33		3.88			3a	30	1a	38
39	A2330	2330	WD2330, cast steel Rolled	0.28	0.69	0.41	3.30	0.12	0.03	2	5, 7	III	39
40	A2335	2340	WD2340	0.38	0.58	0.29	3.11	0.20		4a	32	III	40
41		2340		0.37	0.68	0.21	3.41			3a	31	1a	41
42		2515		0.14	0.51	0.22	5.29			4a	33	1c	42
43			G.M.C. X-3045-A	0.44	0.97	0.31	0.72	0.86	0.01	8b	10	IIa	43
44	A3140	3140	WD3140	0.38	0.72	0.21	1.32	0.49		3a	56	II	44
44a-d				0.39	0.71		1.15	0.75		3g	311	II	44a-d
45		3240		0.41	0.48	0.27	1.68	1.05		4a	33	II	45
46	3312			0.10	0.34	0.20	3.51	1.66	0.06	4a	28, 34	IIIb	46
47	3330			0.29	0.21	0.06	3.25	1.45		9	285	IIc	47
48				0.34	0.22		3.89	1.87		3b	224	IVa	48
49			Modified 3360	0.59	0.34	0.26	3.20	2.26		4a	34	IV	49
50				0.12	0.61	0.27				1c	319	1b	50
51				0.12	0.63	0.25			0.13	1c	320	1b	51
52				0.12	0.60	0.22			0.49	1c	320	IIb	52
53				0.11	0.59	0.25			0.74	1c	321	IIc	53
54			Austenized at 1650	0.22	0.79				0.50	3a	92, 93	IIb	54
			Austenized at 2500									IIc	
55				0.33	0.41			1.96		3d	856	IVa	55
56				0.40	0.42			0.52		3a	45	IIb	56
57				0.38	0.17			0.82		3a	46	IIb	57
58				0.42	0.20			0.21		3a	44	II	58
59				0.29	1.70	1.11	0.10	0.13		1d	11	IIa	59
60				0.43	1.70	0.28		0.17		5a	25	IIa	60
61				0.43	1.65	0.29		0.36		5a	26	IIIb	61
63				0.44	0.65	0.28		0.15		1c	322	1c	63
64				0.41	0.69	0.23		0.29		1c	322	IIa	64
65				0.39	0.67	0.26		0.49		1c	323	IIIc	65

Index of S-Curves or TTT-Curves

ITEM	SPECIFICATION OR KIND			CHEMICAL COMPOSITIONS IN PER CENT						REF.	PAGE	CURVE TYPE	ITEM
	A.I.S.I.	S.A.E.	OTHER	C	MN	SI	NI	CR	MO				
66				0.42	0.55	0.25			0.71	1c	323	IIIb	66
67		4042	WD 4045	0.43	0.90	0.23	0.23	0.27	0.26	4a	20	IIb	67
68	A 4047	4047	WD 4045	0.48	0.94				0.25	3a	43	II	68
69				0.65	0.68				0.10	3a	41	Ia	69
70	4068	4068		0.68	0.87				0.24	3a	42	II	70
71				0.77	0.71	0.29			0.02	1a	852	I	71
72				0.77	0.70	0.29			0.15	1a	853	I	72
73				0.78	0.73	0.28			0.32	1a	854	III	73
74				0.77	0.72	0.28			0.52	1a	855	III	74
75				0.79	0.76	0.27			0.77	1a	856	IIIa	75
76				0.71	0.89	0.29	0.25	0.28	0.94	4a	35	IIIa	76
77			Austenized at 1500 Austenized at 1750	0.97	1.04				0.32	3a	80, 81	II	77
78				1.18	0.76	0.29			0.01	1a	857	Ic	78
79				1.16	0.75	0.29			0.15	1a	858	Ia	79
80				1.19	0.77	0.28			0.33	1a	859	II	80
81				1.15	0.76	0.28			0.53	1a	860	III	81
82				1.18	0.75	0.28			0.78	1a	861	IIIa	82
83	A 4119	4130	} Close to WD X-4130	0.28	0.65	0.19	0.16	0.66	0.22	1d	8	Ia	83
84	A 4130	X-4130		0.33	0.53			0.90	0.18	3a	58	Ia	84
85		4130	Cast steel & rolled	0.32	0.54	0.36	0.07	0.75	0.27	2	8, 11	Ia	85
86		4140		0.38	0.67	0.27	0.08	1.01	0.18	1d	8	IIIc	86
87		4140	Austenized at 1500 Austenized at 2000	0.37	0.77	0.15	0.04	0.98	0.21	3a	59	Ia	87
87x		4140	Homogenized							3d	88, 89	Ia	87x
88		4140		0.38	0.82	0.23	0.29	1.02	0.28	1d	9	IIIc	88
89		4140		0.40	0.68	0.20	0.21	1.00	0.22	1d	9	IIIb	89
90	4142			0.41	0.86	0.30		1.06	0.23	4a	17	IIIb	90
91	4150	4150		0.55	0.60		0.36	1.03	0.19	3a	60	III	91
92		4150		0.46	0.77	0.28	0.15	1.06	0.22	1d	10	IIIc	92
93		4330	Cast steel & rolled	0.33	0.69	0.41	1.41	0.72	0.28	2	12-15	IIIb	93
94		4330		0.31	0.66	0.28	1.67	0.72	0.34	1d	10	IIIb	94
94x		4330	Continuous cooling	0.26	0.60	0.39	1.77	0.70	0.32	5b	1110-B		94x
95		4340		0.42	0.78	0.24	1.79	0.80	0.33	3a	64	IIIa	95
96		"4360"		0.62	0.64	0.67	1.79	0.60	0.32	3a	65	IIIa	96
97		4615		0.17	0.57	0.26	1.73	0.13	0.26	1d	10	IIb	97
98		4635		0.32	0.74	0.31	1.70	0.12	0.23	1d	11	Ic	98
99	A 4640	4640	WD 4640	0.36	0.63	0.19	1.84	0.06	0.23	3a	57	Ic	99
99x		4640	Homogenized	0.34			1.87		0.23	3d	872	Ia	99x
100		4640		0.41	0.76	0.11	1.85		0.25	4a	33	Ia	100
101	A 4815	4815		0.16	0.52		3.36		0.19	3a	96	IIb	101
102		4815	Carburized (48100)	0.97	0.52		3.36		0.20	3a	97	IIIb	102
103				0.32	0.57	0.22	3.38	0.65	0.26	14	5	II	103
104				0.29	0.21	0.06	3.25	1.45		9	285	Ic	104
105				0.31	0.44	0.20	3.40	1.26	0.47	10	2	IVb	105
105x			Krupp	0.15	0.45	0.20	4.03	1.54	0.03	8a	7	IVa	105x
106				0.34			3.89	1.87		3b	224	IVa	106
107				0.33	0.45			1.97		3a	36	Ic	107
108				0.38	0.37			0.57		3a	34	II	108
109	A 5140	5140		0.42	0.68	0.16	0.07	0.93		3a	35	Ia	109
110		52100		1.04	0.35	0.33	0.10	1.35		4a	37	II	110
111		52100	Austenized at 1500 Austenized at 1950	1.02	0.36	0.33		1.41		3a	76, 77	II	111
112		52100	Austenized at 1500 Austenized at 1800	1.06	0.38	0.35		1.35		8b	24	I	112
113		52107		1.01	0.50	0.30		1.21		3g	312	III	113
114			Modified Nitralloy G	0.40	0.64	0.20	0.23	1.81	0.39	4b	224	Ib	114
115				0.33	0.51		0.82	2.32	0.36	11	173	IVb	115
116				0.76	0.27			2.06	0.25	11	174	IV	116
117				1.02	0.33	0.35		2.90		12	17	IVa	117
118				1.04	0.18	0.35		4.0		12	18	IVa	118
119				1.05	0.31	0.35		5.7		12	22	V	119
120				1.02	0.33	0.35		8.8		12	7	IV	120
121		C-Cr, wear resister, 0.23% V		1.50	0.30	0.36		11.0	0.74	4a	38	V	121
122		C-Cr air hardening toolsteel, 0.24% V		1.55	0.27	0.45		11.34	0.53	4b	232	V	122
123			Stainless "12"	0.09	0.44	0.27		12.60		4a	39	IVa	123
124				0.40				13.0		3h	135	IV	124
125			Stainless "A"	0.36	0.43	0.49	0.24	13.50		4a	40	V	125
126	51335			0.35				14.00		3g	316	IV	126
127			Stainless "B"	0.62	0.30	0.17		16.59		4a	40	IV	127
128				0.93	0.49	0.43		18.40	0.55	4a	40	IV	128
129				0.06	0.33	0.20		5.04	0.55	4a	39	IVa	129
130	502		Stainless	0.11	0.38	0.44	0.15	5.46	0.42	3a	61	IVa	130

Index of S-Curves or TTT-Curves

For Typical Curves and Thermal Data See Pages 824 to 831

ITEM	SPECIFICATION OR ALLOY	CHEMICAL COMPOSITIONS IN PER CENT								REF.	PAGE	CURVE TYPE	ITEM
		C	Mn	Si	Ni	Cr	Mo	V	W				
131	S.A.E. 6135	0.35	0.67	0.45		0.98	0.23			5b	94	*	131
132	A.I.S.I. A6145; S.A.E. 6140	0.43	0.74	0.23	0.06	0.92		0.16		3a	62	IIa	132
133	S.A.E. 6150	0.50	0.95	0.19	0.22	1.03		0.20		4a	35	IIa	133
134	S.A.E. 6150	0.53	0.67			0.93		0.18		3a	63	IIa	134
135	Austenized at 1500 Austenized at 1925	0.87	0.30	0.32				0.27		3a	84, 85	Ib	135
136		0.90	0.47	0.42				0.20		3c	771	III	136
137	Oil hardening roller steel	0.85	1.18	0.26		0.50			0.44	4b	230	I	137
138		0.91	1.21	0.29		0.55			0.49	4a	17	I	138
139	WD 74100, fast finishing	1.32	0.28	0.50		0.22			3.51	4b, 4a	230, 37	I	139
140	NE8442	0.39	1.58	0.27	0.05	0.16	0.44			8b	26	IIIc	140
141		0.40	1.43	0.22	0.23	0.29	0.32			4a	36	IIIb	141
142		0.43	1.65				0.36			5a	26	IIIb	142
143	NE8620, 8720	0.18	0.79	0.31	0.52	0.56	0.19			3f	27	Ib	143
144	NE8630	0.33	0.87	0.28	0.48	0.50	0.20			8b	27	II	144
144x	NE8630 (A.M.S. 6355)	0.31	0.94	0.26	0.53	0.59	0.21			5b	496-B	*	144x
145	NE8642	0.42	0.85	0.29	0.50	0.51	0.23			8b	28	IIIc	145
146	NE8642, 8744, 8645	0.44	0.90		0.45	0.54	0.22			3a	66	IIc	146
147	NE8749	0.52	0.85	0.21	0.53	0.50	0.26			4a	35	IIc	147
148	NE8949, 9550	0.52	1.19		0.53	0.51	0.35			3a	67	IIIa	148
149	NE8949	0.49	1.01	0.20	0.54	0.56	0.38			4a	20	IIIb	149
150	NE9420, 9422, 9425	0.24	0.94	0.47	0.30	0.34	0.14			3f	28	IIb	150
151	NE9440 + 0.030 Zr	0.38	1.08	0.70	0.34	0.40	0.11			3a	68	IIa	151
152	NE9540 + 0.015 Zr	0.38	1.45	0.66	0.57	0.52	0.19			3a	69	IIIb	152
153	NE9642 + 0.020 Zr	0.39	1.44	0.56	0.06	0.53	0.0			3a	70	IIa	153
154	NE9650 + 0.025 Zr	0.48	1.30		0.06	0.54	0.01			3a	71	IIa	154
155	Silicon steel	0.50	0.23	0.53		0.05				3a	50	Ic	155
156	Silicon steel	0.29	1.70	1.11	0.10	0.01	0.13			8b	29	IIa	156
157	Silicon steel	0.54	0.23	1.27		0.05				3a	51	Ic	157
158	Silicon steel	0.53	0.23	2.32		0.32				3a	52	II	158
159	Cast iron	2.97	0.82	2.02						17	1370	I	159
160	Ni-Mo cast iron	2.49	0.82	2.56	0.06		0.04			18	1261	III	160
161	Ni-Mo cast iron				1.12		0.10			18	1261	III	161
162	Ni-Mo cast iron	2.55		2.55	1.09		0.26			18	1261	III	162
163	Ni-Mo cast iron	2.58	0.81	2.55	1.02		0.53			18	1261	III	163
164	Ni-Mo cast iron	2.51	0.82	2.66	2.06		0.52			18	1261	III	164
165	Ni-Mo cast iron	2.50	0.81	2.58	3.06		0.51			18	1261	III	165
166	Ni-Mo cast iron	2.52	0.85	2.61	4.07		0.53			18	1261	IIIa	166
167	Ni-Mo cast iron	2.52	0.85	2.56	5.11		0.51			18	1261	IIIa	167
168	Ni-Mo cast iron	2.41	0.80	2.48	1.10		0.91			18	1262	III	168
169	Ni-Mo cast iron	2.53	0.89	2.55	2.03		1.22			18	1262	III	169
170	Ni-Mo cast iron	2.56	0.88	2.55	3.06		1.02			18	1262	IIIa	170
171	Ni-Mo cast iron	2.54	0.91	2.62	4.04		1.05			18	1262	IIIa	171
172	Ni-Mo cast iron	2.53	0.93	2.58	5.02		1.01			18	1262	IIIa	172
173	Cast iron	2.9		2.1						19	840	I	173
174	Molybdenum cast iron	2.9		2.1			0.5			19	840	I	174
175	5% Cr, air hardening steel	0.97	0.48	0.40		4.58	1.04	0.25		4b	231	IVb	175
176	Cr-Mo-W hot work die steel	0.32	0.35	0.95		4.86	1.45		1.29	4b	231	IV	176
176x	Cr-Mo die steel	0.28	0.70	0.47		5.25	0.62			13	1411	IV	176x
177	5-4-4-1 high speed steel	0.83	0.32	0.25		3.89	4.30	1.30	5.79	4b	233	V	177
178	5-4-4-1 high speed steel	0.81	0.24	0.26		4.10	4.69	1.64	5.95	15	185	V	178
179	Hot wear steel	0.82	0.26	0.28		4.14	3.69	1.56	5.59	4a	38	V	179
180	6-6-2 high speed steel	0.80	0.23	0.27		4.07	6.09	1.65	5.70	1b	627	IVb	180
181		0.83				4.15	5.00	1.90	6.40	4	33	IVb	181
182	8 Cr, 7 W	0.54	0.62	0.93		7.83			6.90	4a	21	IV	182
183	Mo high speed + 5.22% Co	0.81	0.41	0.31		4.11	4.29	1.51	5.46	4b	234	IVb	183
184	High speed + 4.72% Co	0.72	0.23	0.43		4.04		1.24	18.38	4b	233	IVb	184
185	18-4-1 high speed	0.71	0.26	0.32		4.04		1.13	18.09	4a	17	IVb	185
186	18-4-1 high speed	0.72	0.27	0.38		4.09		1.25	18.58	4b	232	V	186
187	18-4-1 high speed	0.73	0.21	0.33		4.39	0.18	1.09	17.80	15	186	V	187
188	Cobalt-iron alloys:												
188	0.95% Co	0.95	0.48							3d	858	V	188
189	1.98% Co	0.98	0.49							3d	858	V	189
190	29.50% Co	0.04	0.13	0.10				17.76		20	420	IV	190
191	29.30% Co	0.04	0.13	0.10		1.85		17.21		20	420	IV	191
192	29.10% Co	0.04	0.17	0.13		2.76		17.33		20	420	IV	192

*Map of transformation during continuous cooling.

tenite Decomposition in High Speed Steel," Am. Soc. Metals Trans., Vol. 31, 1943, p. 161.

16 — J. V. Russell and F. T. McGuire, "A Metallographic Study of the Decomposition of Austenite in Manganese Steels," Am. Soc. Metals Trans., Vol. 33, 1944, p. 103.

17 — F. B. Rote, W. C. Truckenmiller and W. P. Wood, "Electrical Resistance Method for the Determination of Isothermal Austenite Transformations," Am. Soc. Metals Trans., Vol. 30, 1942, p. 1359.

18 — R. A. Flinn, M. Cohen and J. Chipman, "The Acicular Structure in Nickel-Molybdenum Cast Irons," Am. Soc. Metals Trans., Vol. 30, 1942, p. 1255.

19 — D. B. Oakley and J. F. Oesterle, "Dilatometric Studies in the Transformation of Austenite in a Molybdenum Cast Iron," Am. Soc. Metals Trans., 1940, p. 832.

20 — W. P. Sykes, "The Ar' Reaction in Some Iron-Cobalt-Tungsten Alloys and the Same Modified With Chromium," Am. Soc. Metals Trans., 1945, p. 415.

21 — R. A. Grange and J. M. Kiefer, "Transformation of Austenite on Continuous Cooling and Its Relation to Transformation at Constant Temperature," Am. Soc. Metals Trans., Vol. 29, 1941, p. 85.

22 — W. T. Griffith, L. B. Pfeil and N. P. Allen, Sections 12 and 13, Second Report of Alloy Steels Research Committee, Iron Steel Inst., 1939 (Abstract in Metal Progress, Vol. 36, 1939, p. 158.)

23 — E. S. Rowland and S. R. Lyle, "Measurement of Case Depths by Martensite Formation," Metal Progress, Vol. 47, May 1945, p. 909.

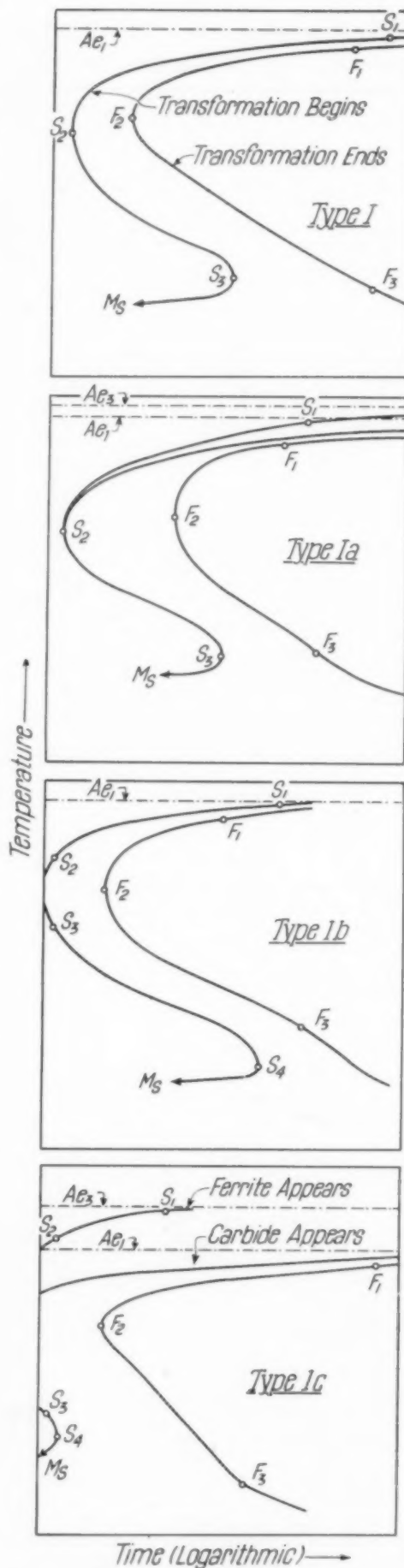
24 — Walter H. Bruckner and Jun Hino, "The Rate of Spheroidization and the Physical Properties of Pearlitic Malleable Iron After Isothermal Quenching," Trans. Am. Foundrymen's Assoc., Vol. 52, June 1945, p. 1189.

25 — J. Paul Deringer, "Bearing Races Improved by Isothermal Treatment," Metal Progress, Vol. 48, July 1945, p. 80.

26 — Benjamin F. Shepherd, "Martempering," Metal Progress, Vol. 46, August 1944, p. 309; "Martempering," Iron Age, Jan. 28, p. 50, and Feb. 4, 1943, p. 45.

27 — Harold J. Babcock, "Isothermal Quench Baths Applied to Commercial Practice," Iron Age, Vol. 153, Feb. 3, 1944, p. 44; Feb. 10, 1944, p. 62.

28 — "Austempering in Successful Commercial Operation," Heat Treating and Forging, Oct. 1939, p. 499.



ITEM	AUSTEN- IZED AT	GRAIN SIZE	AE ₁	AE ₁ IP, AC
Type I				
15				1340
16	1650	6		1340
18	1385			1370
19	1625	4-5		1340
20	2000	2-3		
20x				1330
24				1355
25				1350
26				1350
71	1550	8		1352
72	1550	8		1357
137	1450			1370
138	1425			
139				
159	1600			
173	1525			
174	1525			
Type Ia				
6	1670	7-8	1405	1340
13	1500	5-6	1360	1325
14	1670	7	1370	1330
29x		7-8		
30	1650		1365	1300
31	1650		1380	1320
32				
33				
38	1480	8-10	1310	1190
40	1450	7-8	1350	1225
69	1600	6-8 1/2	1370	1330
79	1700†	8		1352
112				

ITEM	AUSTEN- IZED AT	GRAIN SIZE	AE ₁	AE ₁ IP, AC
Type Ib				
1	1700			
9			1350	
10				
22	1450			1360
23	1410			1370
35				
50	1700			
51	1700			
113	1500			1385
135a	1500†	11		1335
Type Ic				
2†	1660	7-8		1340
2	1660			
3	1550	mixed	1475	1330
4	1700			
5a	1425			
5b	1370		1350	
7	1670	7-8	1390	1340
8				
11	1600	6-9	1360	1330
12	1500	5-6	1355	1320
21	1670	7-8		1340
36	1480	8-10	1370	1315
37	1480	8-10	1340	1280
42	1450			
63	1550			
78	1700†	8		1352
155	1550	2 + 7	1430	1345
157	1600	3 + 7	1495	1380

†Cast steel.

AE
IF*, AC

1340
1340
1370
1340
1330
1355
1350
1350
1352
1357
1370

ITEM	S ₁		S ₂		S ₃		M _s	F ₁			F ₂			F ₃			ITEM	
	°F.	TIME	°F.	TIME	°F.	TIME		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.		
Steels With Type I Transformation Curves																		
15	1340	10 ³ s.	1020	0.9 s.	460	500 s.		1315	10 ³ s.	C-5	1060	6 s.	C-41	315	10 ³ s.	C-62	15	
16	1310	10 ³ s.	1020	0.9 s.	530	10 ³ s.	445	1290	10 ³ s.	C-11	1050	5 s.	C-39	470	10 ³ s.	C-56	16	
18	1350	60 m.	1115	2 s.				1330	60 m.	C-8	1150	8 s.					18	
19	1330	10 ³ s.	1050	0.8 s.	500	250 s.	425	1310	10 ³ s.	C-15	1040	4 s.	C-41	460	10 ³ s.	C-57	19	
20	1290	10 ³ s.	1050	8.5 s.	520	10 ³ s.	Curve for 50% transformation											20
20x	1225	20 s.	1000	2.5 s.	650	100 s.		1220	100 s.		1100	20 s.		640	10 ³ s.		20x	
24	1300	15 s.	1000	1.5 s.	420	2 hr.	100	1300	100 s.	C-35	1100	5 s.	C-47	280	10 d.	C-63	24	
25	1335	10 ³ s.	1000	1.5 s.	400	66 m.	325	1330	10 ³ s.		1100	5 s.		500	10 ³ s.		25	
26	1250	10 ³ s.	1000	2.5 s.	550	10 ³ s.		1275	10 ³ s.		1025	30 s.		630	10 ³ s.		26	
71	1295	10 ³ s.	1050	1 s.	480	5 m.	400	1280	10 ³ s.	V-209	1080	4.5 s.	V-390	480	1 hr.	V-689	71	
72	1290	10 ³ s.	980	3 s.	480	200 m.	400	1275	10 ³ s.	V-260	1040	9 s.	V-376	450	10 ³ s.	V-710	72	
137	1350	1 hr.	1095	9 s.	605	1 m.	390	1340	6 hr.	C-14	710	15 m.	C-44	400	5 hr.	C-60	137	
138	1340	4 hr.	1175	15 s.				1300	8 hr.	C-17	1220	30 m.	C-25				138	
139	1330	1 hr.	1050	1.6 s.	400	12 s.	340	1300	1 hr.	C-22	1100	8 s.	C-42	350	15 hr.	C-63	139	
159	1275	40 s.	960	8 s.	620	30 s.	440	1280	800 s.		970	200 s.		600	10 ³ s.		159	
173	1000	2.9 m.	800	0.7 m.	500	2.5 m.	400	1000	3 hr.		800	18 m.		400	8 hr.		173	
174	1000	2 m.	800	0.7 m.	500	3 m.	400	1000	200 m.		800	18 m.		400	17 hr.		174	
Steels With Type Ia Transformation Curves																		
6	1370	10 ³ s.	970	0.6 s.	660	12 s.	580	1270	10 ³ s.		1010	4 s.	C-28	510	10 ³ s.	C-52	6	
13	1335	10 ³ s.	1080	1.5 s.	530	1 m.	520	1290	10 ³ s.	C-19	1120	9 s.	C-33	600	10 ³ s.	C-50	13	
14	1320	10 ³ s.	960	0.75 s.	555	90 s.	490	1255	10 ³ s.		1000	20 s.	C-35	590	10 ³ s.	C-50	14	
29x	1350	10 ³ s.	950	1.4 s.	680	3 s.	500	1180	10 ³ s.	C-6	880	75 s.	C-26	540	10 ³ s.	C-47	29x	
30	1300	10 ³ s.	980	6 s.	580	10 ³ s.		1290	10 ³ s.		840	500 s.	V-320	570	83 m.		30	
31	1290	30 s.	930	3 s.	660	10 s.		1280	10 ³ s.		930	1 m.	V-275	660	400 s.	V-440	31	
32	1300	10 ³ s.	1000	8 s.	700	100 s.	50% transformation curve											32
33	1190	10 ³ s.	950	7 s.	600	250 s.	50% transformation curve											33
38	1280	10 ³ s.	930	1.5 s.	580	250 s.	500	1140	10 ³ s.	C-14	990	25 s.	C-25	650	10 ³ s.	C-45	38	
40	1320	10 ³ s.	900	0.8 s.	590	19 s.	470	1150	10 ³ s.	C-11	915	1 m.	C-24	450	10 ³ s.	C-50	40	
69	1340	10 ³ s.	980	0.8 s.	580	1 m.	540	1270	10 ³ s.	C-22	1000	9 s.	C-36	600	10 ³ s.	C-54	69	
79	1400	1 m.	1050	2 s.	300	5½ hr.	240	1290	10 ³ s.	V-260	1050	11 s.	V-487	410	10 ³ s.	V-818	79	
112	1350	10 m.	1120	2.5 s.	400	15 m.	300	1340	1 hr.	C-18	1150	25 s.	C-36	405	2.5 hr.	C-62	112	

AE
IF*, AC

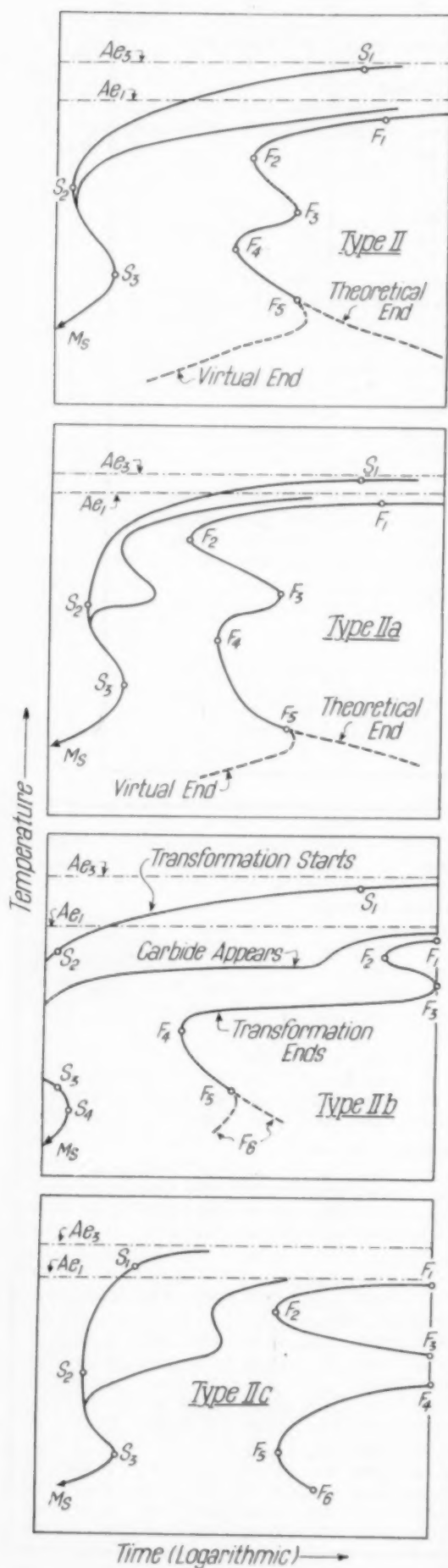
1360
1370
1385
1335

1340
1330
1320
1340
1315
1280

1352
1345
1380

ITEM	S ₁		S ₂		S ₃		S ₄		M _s	F ₁			F ₂			F ₃			ITEM
	°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
Steels With Type Ib Transformation Curves																			
1	1490	1 s.								1230	10 ³ s.	V-177	1200	20 s.	V-155	900	1 s.	V-189	1
9	1300	10 ³ s.	1110	0.5 s.	780	0.5 s.	430	1½ s.	250	1340	10 ³ s.		1050	1 s.		500	10 ³ s.		9
10	1270	10 s.	1100	2 s.	920	2 s.	480	60 s.	400	1300	250 s.	C-16	1000	3 s.	C-33	500	10 ³ s.	C-50+	10
22	1360	1 hr.	1150	1.5 s.	945	1.5 s.	385	15 m.	385	1325	60 m.		1050	3 s.	C-42	440	60 m.	C-60	22
23	1355	1 hr.	1150	3 s.						1345	60 m.	C-8	1150	20 s.					23
35	1280	10 ³ s.	960	0.6 s.	600	40 s.	50% transformation curve.												35
50	1500	10 s.	1350	1 s.						1210	10 ³ s.	V-158	800	1 s.	V-220				50
51	1500	6 s.	1320	1 s.						1250	10 ³ s.	V-170	1060	10 ³ s.	V-179	810	1 s.	V-240	51
113	1360	1 hr.	1130	1.5 s.	1020	1.5 s.	400	4 m.	400	1350	4 hr.	C-18	1120	12 s.	C-36	300	8 hr.	C-64	113
135a	1305	10 ³ s.	1100	0.5 s.	1000	0.5 s.	475	300 s.	420	1280	10 ³ s.	C-8	1050	3 s.	C-38	600	10 ³ s.	C-50+	135a
Steels With Type Ic Transformation Curves																			
2†	1340	10 s.	1235	1 s.					550	1300	10 ³ s.	C-2	990	3 s.	C-20	520	10 ³ s.	C-42	2†
2	1320	10 s.	1140	1 s.					650	1255	10 ³ s.	C-4	1030	2.5 s.	C-17	550	10 ³ s.	C-40	2
3	1465	50 s.	1330	0.5 s.	810	0.5 s.	720	0.8 s.	665	1280	10 ³ s.	C-9	1080	3 s.	C-25	645	10 ³ s.	C-45	3
4	1350	10 s.	1215	1 s.	780	1 s.	630	2.5 s.	500	1250	10 ³ s.	V-194	1060	4¼ s.	V-262	500	10 ³ s.	V-566	4
5a	1365	60 m.	1240	1 s.						1300	60 m.	C-3	1110	3 s.	C-21				5a
5b	1330	60 hr.	1250	15 s.						1315	60 hr.		1250	2 m.					5b
7	1370	10 ³ s.	1060	0.5 s.	980	0.5 s.	685	6 s.	610	1300	10 ³ s.		1050	1.5 s.	C-27	505	10 ³ s.	C-50	7
8	1300	10 ³ s.	1060	1 s.	640	100 s.	This curve for 50% transformation only.												8
11	1345	10 ³ s.	1150	0.5 s.	850	0.5 s.	565	25 s.	520	1280	10 ³ s.	C-23	1090	3 s.	C-34	600	10 ³ s.	C-53	11
12	1350	10 ³ s.	1120	0.5 s.	975	0.5 s.	538	40 s.	515	1270	10 ³ s.	C-15	1100	6 s.	C-33	580	10 ³ s.	C-52	12
21	1580	100 s.	1200	0.5 s.	860	0.5 s.	380	1 hr.	300	1290	100 s.	C-27	1040	2 s.	C-45	615	10 ³ s.	C-55	21
36	1360	10 ³ s.	1110	0.5 s.	835	0.5 s.	615	12 s.	550	1250	10 ³ s.	C-4	970	1.6 s.	C-28	550	10 ³ s.	C-50	36
37	1310	10 ³ s.	1050	0.5 s.	850	0.5 s.	590	15 s.	540	1220	10 ³ s.	C-11	1000	2.5 s.	C-20	580	10 ³ s.	C-51	37
42	1170	1 hr.	1110	1 s.						900	15 hr.	C-14	800	8 m.	C-22				42
63	1360	20 s.	1120	1 s.	900	1 s.	650	3 s.	500	1240	10 ³ s.	V-181	970	9 s.	V-265	500	10 ³ s.	V-566	63
78	1400	50 s.	1165	1 s.	1000	1 s.	305	8 hr.	245	1300	500 s.	V-254	1050	4.5 s.	V-502	415	10 ³ s.	V-800	78
155	1410	100 s.	1200	0.5 s.	800	0.5 s.	610	3 s.	575	1270	100 s.	C-17	1000	4 s.	C-28	495	10 ³ s.	C-53	155
157	1480	100 s.	1190	0.5 s.	900	0.5 s.	600	6 s.	580	1100	100 s.	C-20	1120	10 s.	C-30	600	500 s.	C-52	157

†Probably too low to dissolve all carbides.



ITEM	AUSTEN- IZED AT	GRAIN SIZE	A _{E2}	A _{E1} IF°, AC ₁	S ₁		S ₂		S ₃		M	ITEM
					°F.	TIME	°F.	TIME	°F.	TIME		
Type II Curves												
29*	1550	7 + 2	1430	1295	1405	10's.	1000	0.8 s.	680	4 s.	30	29
44	1550	7-8	1390	1305	1370	10's.	1050	1.2 s.	670	8 s.	40	44
44a	1550	7-8			1100	5 s.	1000	2.5 s.	900	4 s.	44	44
44b	1650	6-6.5			1100	8 s.	975	3.5 s.	900	5.5 s.	44	44
44c	1700	5-6			1100	8.2 s.	960	4.6 s.	900	6.1 s.	44	44
44d	1800	3.5-4			1100	9 s.	975	6 s.	900	7 s.	44	44
45	1450				1300	1.5 m.	900	5 s.			45	45
58	1600	5-6	1440	1330	1420	10's.	900	0.6 s.	635	2 s.	58	58
68	1500	6-7	1405	1310	1375	10's.	970	1.4 s.	590	12 s.	58	68
70	1650	7-8	1370	1330	1350	10's.	920	2.5 s.	500	80 s.	70	70
77a	1550†	7-8		1330	1400	10's.	900	5 s.	380	50 m.	77	77
80	1700†	8		1357	1390	1 m.	1100	4 s.	300	5.5 hr.	80	80
103	1560				975	7 hr.	805	40 s.	660	70 s.	103	103
108	1600	5-6	1455	1380	1430	10 s.	925	0.6 s.	660	2 s.	108	108
110	1400				1385	1 hr.	1150	1.5 s.			110	110
111a	1550	9		1345	1345	100 s.	1050	3 s.	530	50 s.	111	111
144		7-8			1160	10 s.	950	3.5 s.	800	6 s.	144	144
158	1800	3 + 7		1430	1540	10 s.	1120	1 s.	645	8 s.	158	158
Type IIa Curves												
43	1550	8-9		1320	1250	20 s.	970	2 s.	615	11 s.	43	43
59					1300	600 s.	940	20 s.	650	50 s.	59	59
60	1550	7-8		1317	1320	10's.	950	4 s.	625	45 s.	60	60
64	1550				1350	13.5 s.	960	1.2 s.	710	4 s.	64	64
83					1300	10 s.	920	2 s.	710	3.5 s.	83	83
84	1550	9-10	1470	1360	1460	10's.	1000	1.3 s.	700	6 s.	84	84
85a	1660				1410	70 s.	950	2.1 s.	735	3 s.	85	85a
85b	1660				1400	40 s.	920	2 s.	720	3 s.	85	85b
87a	1550	7-8	1445	1365	1430	10's.	880	3 s.	700	6 s.	87	87a
87b	2000	2-3	1445	1365	1405	10's.	920	2.5 s.	705	6 s.	87	87b
87x		8			1410	10's.	920	2.5 s.	720	5 s.	87	87x
99x		8			1360	10's.	950	1.3 s.	720	2.5 s.	99	99x
100	1450				1300	2 m.	900	3 s.			100	100
109a	1550†	6-7	1425	1360	1410	10's.	1000	1.8 s.	670	5 s.	109	109a
132	1550	8	1445	1370	1420	10's.	940	2 s.	650	10 s.	132	132
133	1450				1400	15 m.	1175	10 s.			133	133
134	1550	9		1370	1370	10's.	900	3 s.	590	35 s.	134	134
151	1575	10-11	1480	1280	1400	500 s.	1000	1.2 s.	675	5 s.	151	151
153	1525	9-10	1425	1350	1360	50 s.	1000	1 s.	590	8 s.	153	153
154	1525	9	1400	1350	1345	10's.	1000	2 s.	575	30 s.	154	154
156					1300	700 s.	950	20 s.	700	40 s.	156	156

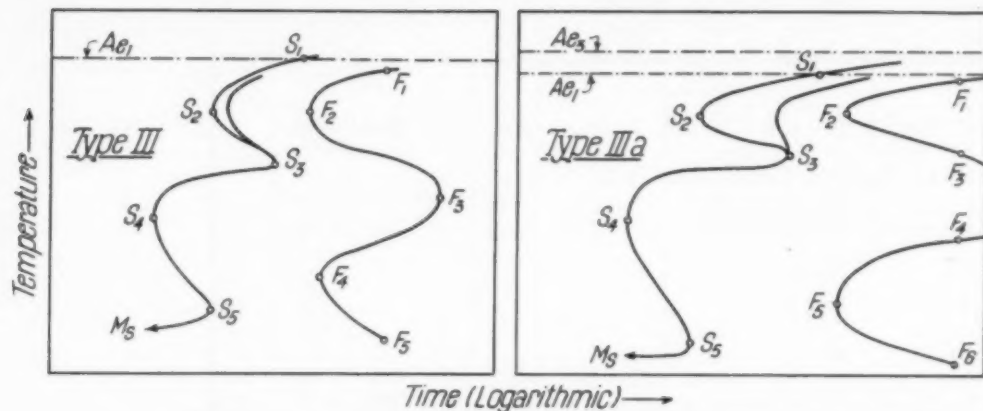
ITEM	AUSTEN- IZED AT	GRAIN SIZE	A _{E2}	A _{E1} IF°, AC ₁	S ₁		S ₂		S ₃		M	ITEM
					°F.	TIME	°F.	TIME	°F.	TIME		
Type IIb Curves												
52	1700				1500	6 s.	1320	1 s.			52	52
54a	1650	8-9	1495	1330	1480	50 s.	1015	0.5 s.			54	54a
56	1600	6-7	1460	1340	1440	10's.	900	0.8 s.	690	2 s.	56	56
57	1600	6-7	1470	1330	1430	10's.	880	0.7 s.	660	2 s.	57	57
67	1500				1360	8 m.	1180	1 s.	680	1 s.	67	67
97					1300	45 s.	1040	1 s.	740	1 s.	97	97
101	1650	8-9	1425	1230	1400	10's.	1110	0.5 s.			101	101
143	1650	9-10	1530	1340	1520	10 hr.	1360	0.5 s.			143	143
150	1650	7-8	1540	1340	1510	10's.	1350	0.5 s.			150	150
Type IIc Curves												
47	1550	7	1350	1310	1350	10's.	940	14 s.	705	150 s.	47	47
53	1700				1500	7 s.	1270	1 s.			53	53
54b	2500	1-2	1495	1325	1480	50 s.	980	0.5 s.			54	54b
77b	1750†	5-6		1325	1370	500 s.	915	6 s.	330	4 hr.	77	77b
98	1550				1300	800 s.	925	2 s.	640	22 s.	98	98
99		7-8	1390	1280	1370	10's.	920	1.8 s.	700	4 s.	99	99
104	1550	7	1350	1310	1350	10's.	940	35 s.	705	2 m.	104	104
107	1600	6-7	1470	1415	1450	200 s.	955	2 s.	705	7 s.	107	107
146	1550	9-10	1430	1320	1360	10 s.	1000	1.8 s.	690	5 s.	146	146
147	1500			1355*	1350	8 hr.	1125	16 s.			147	147

*S₁ for item 67 is at 600° and 8 s.; for item 97 is at 680° and 1.3 s.

TIME	M	ITEM	F ₁			F ₂			F ₃			F ₄			F ₅			ITEM
			°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
Steels With Type II Transformation Curves																		
4 s.	50	29*	1220	10's.	C-8	1100	5 m.	C-15	905	20 m.	C-21	770	150 s.	C-35	470	10's.	C-48	29*
8 s.	40	44	1265	10's.		1120	55 s.	C-20	1000	350 s.	C-21	895	110 s.	C-26	560	10's.	C-49	44
4 s.	40	44a																44a
5.5 s.	40	44b																44b
8.1 s.	40	44c																44c
7 s.	40	44d																44d
		45	1215	15 hr.	C-7	1000	1 hr.	C-21	900	2.5 m.								45
2 s.	50	58	1275	10's.		1200	220 s.	C-9	1120	100 s.	C-15	940	14 s.	C-25	610	10's.	C-49	58
12 s.	50	58	1250	10's.		1180	30 m.	C-13	1070	500 m.	C-18	900	1 m.	C-29	595	10's.	C-50	68
90 s.	40	70	1265	10's.		1200	50 m.	C-21	1050	10's.	C-28	870	110 s.	C-34	480	10's.	C-56	70
90 m.	30	77a	1300	14 hr.	C-15	1170	20 m.	C-30	975	10 hr.	C-35	800	23 m.	C-43	380	10's.	C-63	77a
5 hr.	30	80	1300	1 hr.	V-267	1200	200 s.	V-353	1100	150 s.	V-435	950	45 s.	V-463	415	10's.	V-820	80
70 s.	30	83	845	17 hr.		720	33 m.		390	10's.								103
2 s.	30	88	1320	10's.	C-6	1140	25 s.	C-20	1000	90 s.	C-20	870	30 s.	C-30	500	10's.	C-49	108
		90	1335	1 hr.	C-13	1200	35 s.	C-23										110
50 s.	40	111a	1310	10's.	C-18	1180	30 s.	C-31	900	5 m.	C-35	800	3 m.	C-41	540	10's.	C-58	111a
6 s.	40	44	1175	200 s.	V-227	1060	100 m.	V-652	900	30 s.	V-284	800	40 s.	V-314				144
8 s.	50	58	1360	100 s.		1200	13 s.	C-35	800	100 m.	C-38	800	10's.	C-51	400	14 hr.	C-55	158
Steels With Type IIa Transformation Curves																		
11 s.	50	43	1270	10's.	C-15	1190	2 m.	C-23	910	8.3 hr.	C-25	750	10's.	C-36	590	5.5 hr.	C-46	43
50 s.	50	59	1200	10's.		1100	150 m.		620	33 m.		500	10's.					59
45 s.	50	60	1235	10's.	C-21	1125	50 m.	C-24	890	90 s.	C-30	600	10's.	C-51				60
4 s.	50	64	1260	10's.	V-177	1200	10's.	V-198	1100	6 hr.		925	12 s.	V-288	500	10's.	V-540	64
5.5 s.	50	63	1300	10's.	C-(-4)	1220	500 s.	C-5	1000	10's.	C-16	850	40 s.	C-25	600	100 s.	C-47	83
6 s.	60	64	1320	10's.	C-12	1250	3 m.	C-15	1000	4 hr.	C-24	790	90 s.	C-37	585	10's.	C-44+	84
3 s.	50	65a	1335	10's.	C-6	1250	7 m.	C-10	1040	7.2 hr.	C-21	800	50 s.	C-36	500	10's.	C-47	85a
3 s.	60	65b	1320	10's.	C-8	1240	6 m.	C-13	1070	8.3 hr.	C-20	780	40 s.	C-36	520	10's.	C-46	85b
6 s.	50	67a	1310	10's.	C-10	1220	400 s.	C-20	1000	5.5 hr.	C-29	700	210 s.	C-44	450	10's.	C-52	87a
6 s.	50	67b	1310	10's.	C-8	1210	10's.	C-26	1000	10 hr.	C-29	705	210 s.	C-45	500	30 m.	C-50+	87b
5 s.	50	67x	1300	10's.		1225	400 s.	C-20	990	5.5 hr.	C-29	800	150 s.	C-37	480	30 m.	C-51	87x
2.5 s.	50	69x	1260	10's.		1160	4 hr.	C-4	1075	4.7 hr.	C-12	900	32 s.	C-23	510	30 m.	C-48	99x
		70				1260	29 hr.		1050	3.5 hr.	C-21	900	2.5 m.					100
5 s.	40	69a	1320	10's.	C-13	1200	40 s.	C-24	1000	800 s.	C-26	830	110 s.	C-35	530	10's.	C-51	109a
10 s.	40	72	1315	10's.	C-13	1200	50 s.	C-26	950	25 m.	C-31	780	4 m.	C-38	460	10's.	C-52	132
		73	1300	6 m.	C-12	1220	1.5 m.	C-22	1100	10 m.								133
35 s.	50	74	1280	10's.	C-20	1200	50 s.	C-31	910	33 m.	C-31	720	400 s.	C-45	600	10's.	C-52	134
5 s.	50	81	1270	10's.		1180	9 m.	C-18	850	5.5 hr.	C-30	670	10's.	C-42	600	20 m.	C-50	151
8 s.	50	83	1300	10's.	C-7	1180	40 s.	C-21	940	40 m.	C-29	705	22 m.	C-42	600	40 m.	C-50	153
30 s.	50	84	1275	10's.	C-15	1170	80 s.	C-30	845	45 m.	C-33	750	24 m.	C-40	600	1 hr.	C-49	154
40 s.	50	86	1180	11 hr.		1090	83 m.	C-17	900	50 m.	C-20	650	30 m.	C-48	540	10's.		156

TIME	ITEM	F ₁			F ₂			F ₃			F ₄			F ₅			ITEM
		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
Steels With Type IIb Transformation Curves																	
	82	1320	10's.	V-170	1200	5.5 hr.	V-175	1090	8.3 hr.	V-195	800	1 s.	V-250				52
	84a	1280	10's.		1200	1 hr.	C-8	1080	1 d.	C-15	910	30 m.	C-25				54a
2 s.	86	1300	10's.		1200	83 m.	C-16	1045	16.6 hr.	C-22	840	1 m.	C-35	520	10's.	C-51	56
2 s.	87	1330	10's.	C-3	1240	50 m.	C-12	1100	1.3 d.	C-19	895	18 s.	C-26	680	10's.	C-45	57
1 s.	88	1300	9 hr.	C-9	1200	30 m.	C-13	1025	20 hr.	C-22	680	4 m.	C-32	500	9 m.	C-52	67
1 s.	89	1220	14 hr.		1150	117 m.	C-4	1060	14 hr.	C-17	1010	14 hr.	C-30	850	28 s.	C-30	97
	91	1170	10's.		1100	1.4 d.	C-4	980	9.3 d.	C-10	800	70 s.	C-30	560	500 s.	C-40	101
	93	1300	10's.	C-4	1200	10's.	C-12	1025	2.1 d.	C-19	850	50 s.	C-30	700	3 m.	C-36+	143
	90	1300	10's.	C-7	1200	500 s.	C-12	1080	1 hr.	C-17	830	1 m.	C-35	700	200 s.	C-43	150
Steels With Type IIc Transformation Curves																	
50 s.	87	1230	10's.	V-165	1105	3 hr.	C-38	1070	10's.		870	10's.	C-51	800	500 s.	C-39	47
	83	1370	10's.		1250	8.3 hr.	V-166	1090	10's.	V-219	1030	10's.	V-215	840	1 s.	V-270	53
	84b	1270	10's.		1200	5 hr.	C-8	1140	10's.	C-13	1025	10's.	C-20	910	1 m.	C-27	54b
1 hr.	87b	1315	10's.	C-19	1200	83 m.	C-31	1100	10's.	C-35	770	10's.	C-43	680	1 hr.	C-50	77b
22 s.	88	1200	11 hr.		1125	100 m.	C-10	1030	11 hr.	C-11	1000	11 hr.	C-18	860	80 s.	C-26	98
4 s.	89	1250	10's.	C-3	1130	30 m.	C-9	1025	10's.	C-14	970	10's.	C-14	760	200 s.	C-37	99
2 m.	94	1230	10's.		1105	3.6 hr.	C-38	1070	10's.		870	10's.		810	500 s.	C-39	104
7 s.	97	1390	10's.		1280	250 s.	C-14	1025	10's.	C-27	860	10's.	C-33	645	300 s.	C-46	107
5 s.	96	1300	10's.	C-0	1200	15 m.	C-16	1060	10's.	C-23	865	10's.	C-26	600	15 m.	C-49	146
	97	1300	8 hr.	C-11	1200	13 m.	C-21	1100	5 hr.	C-26							147

*Not homogeneous. †Probably too low to dissolve all carbides.

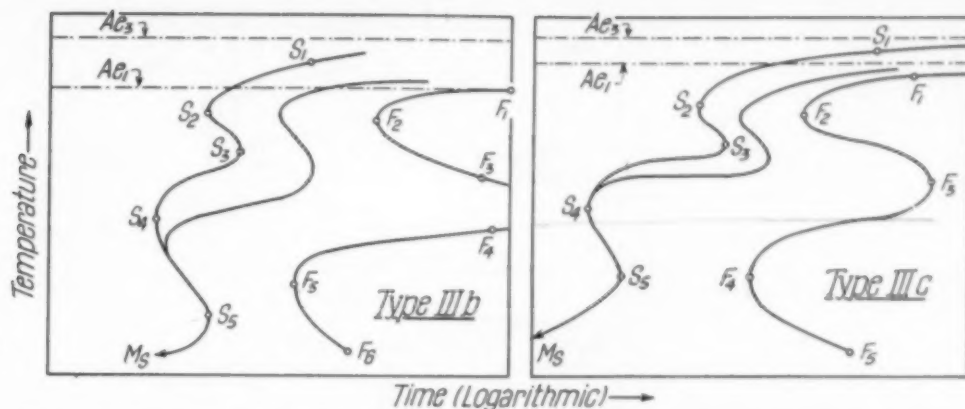


ITEM	AUSTEN- IZED AT	GRAIN SIZE	AE ₀	AE ₁ IF°, AC ₁	S ₁	S ₂	S ₃	S ₄	S ₅	M ₅	ITEM
					°F.	TIME	°F.	TIME	°F.	TIME	
Steels With Type III Transformation Curves											
34	1650		1310	1255	1250	10 ^s .	1020	5 m.	900	10 ^s .	34
39a	1660				1320	10 ^s .	900	3 s.	670	10 s.	39a
39b	1660				1190	10 m.	970	2 s.	740	7 s.	39b
40	1400				1300	1 hr.	1050	20 s.			40
73	1550	8		1352	1300	83 m.	1135	100 s.	980	4.5 s.	73
74	1550	8		1352	1260	10 ^s .	1150	500 s.	970	5 s.	74
81	1700†	8		1357	1400	100 s.	1150	11 s.	1050	20 s.	81
91	1550	7-8		1355	1360	500 s.	1200	8 s.	1050	250 s.	91
111b	1950	3		1345	1420	50 s.	1180	3 s.	940	80 s.	111b
112b	1800				1350	1 hr.	1100	15 s.	910	7 m.	112b
135b	1925	2-3		1335	1320	10 ^s .	1100	4.5 s.	1020	5 s.	135b
136	2000	2-3			1300	5 m.	1150	13 s.	600	10 ^s .	136
160	1600				1300	25 s.	1125	8 s.	930	30 s.	160
161	1600				1300	55 s.	1200	25 s.	940	2 hr.	161
162	1600				1300	1 m.	1210	40 s.	930	20 m.	162
163	1600				1300	70 s.	1220	50 s.	950	50 m.	163
164	1600				1320	500 s.	1210	3 m.	950	100 m.	164
165	1600				1310	33 m.	1200	400 s.	840	10 ^s .	165
168	1600				1320	200 s.	1225	2 m.	940	5.5 hr.	168
169	1600				1300	10 ^s .	1200	200 s.	850	36 hr.	169
Steels With Type IIIa Transformation Curves											
75	1550	8		1352	1300	1 hr.	1220	800 s.	1040	33 m.	75
76	1400				1315	1 hr.	1200	150 s.	1150	4.5 m.	76
81	1700†	8		1357	1375	100 s.	1200	30 s.	1100	40 s.	81
96	1800†	7-8		1290	1335	10 ^s .	1120	5 m.	975	750 s.	96
148	1550	7-8	1380	1310	1300	10 ^s .	1190	80 s.	1070	15 m.	148
166	1600				1300	5.5 hr.	1180	8 m.	800	2.3 d.	166
167	1600				1290	10 ^s .	1150	50 m.	790	5.8 d.	167
170	1600				1310	10 ^s .	1190	8 m.	800	3.5 d.	170
171	1600				1275	10 ^s .	1180	10 ^s .	800	5.8 d.	171
172	1600				1270	14 hr.	1150	1 hr.	800	8.1 d.	172
Steels With Type IIIb Transformation Curves											
27	1650				1300	3 m.	1250	140 s.	1130	5 m.	27
28					1300	70 s.	1200	40 s.	1100	110 s.	28
46	1450				1300	1 hr.	1180	45 s.	820	1 s.	46
61	1550	8		1317	1305	83 m.	1210	2 m.	1100	10 ^s .	61
66	1550				1375	50 s.	1300	25 s.	1175	200 s.	66
89							1300	30 s.	1150	18 s.	89
90	1500				1425	45 m.	1220	20 s.	1150	2 m.	90
93a	1660				1300	200 s.	1220	55 s.	1110	220 s.	93a
93b	1660				1300	10 ^s .	1215	45 s.	1130	2 m.	93b
94					1300	33 m.	1200	200 s.	1050	5.5 hr.	94
95	1550	7-8	1375	1300	1350	10 ^s .	1200	3 m.	1000	8.3 hr.	95
102	1800	7		1245	1400	10 ^s .	1145	15 s.	1010	25 s.	102
141					1320	2 hr.	1225	2 m.	1100	15 m.	141
142	1550	8		1317	1315	10 ^s .	1210	2 m.	1100	10 ^s .	142
149	1500				1320	8 hr.	1200	4 m.	1050	1 hr.	149
152	1525	10-11	1425	1280	1375	10 ^s .	1200	40 s.	1010	4 m.	152
Steels With Type IIIc Transformation Curves											
65	1550				1370	50 s.	1280	12.5 s.	1200	30 s.	65
86									1300	30 s.	86
88					1300	90 s.	1250	40 s.	1100	100 s.	88
92					1300	150 s.	1225	90 s.	1040	25 m.	92
140		8-9			1200	10 ^s .	1050	10 ^s .	940	18 s.	140
145		7-8					1175	30 s.	1115	70 s.	145

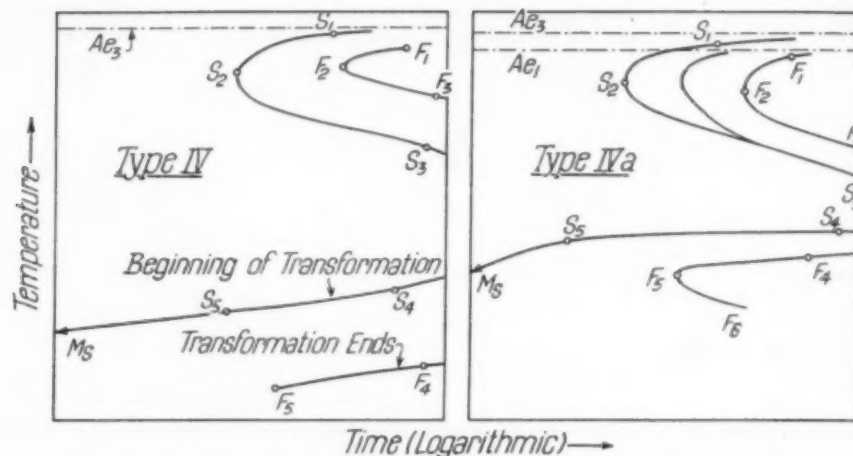
Footnotes to Table:

†Probably too low to dissolve all carbides.

‡The original reference (3a) should be consulted.

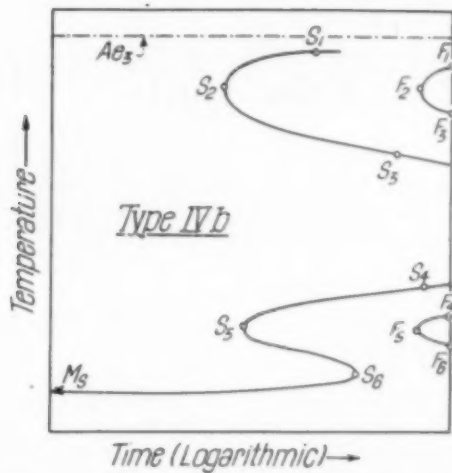


ITEM		F ₁			F ₂			F ₃			F ₄			F ₅			F ₆			ITEM
		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
Steels With Type III Transformation Curves																				
34	34	1190	10's.		1020	66 m.	V-265	660	92 d.		510	11.5 d.	V-480							34
39a	39a	1130	10's.	C-7	1050	5.5 hr.	C-10	980	14 hr.	C-15	825	250 s.	C-28	460	10's.	C-46				39a
39b	39b	1100	10's.	C-7	1050	2.5 hr.	C-10	960	14 hr.	C-15	830	150 s.	C-25	480	10's.	C-43				39b
40	40	1150	2 hr.	C-9	1050	10 m.	C-16													40
73	73	1285	10's.	V-197	1200	10's.	V-278	1125	15 m.	V-330	940	40 s.	V-380	460	10's.	V-713				73
74	74	1290	10's.	V-215	1200	1 hr.	V-282	1050	11 hr.	V-296	925	1 m.	V-358	450	10's.	V-700				74
81	81	1315	83 m.	V-258	1240	10's.	V-298	1040	8.3 hr.	V-380	920	90 s.	V-450	420	10's.	V-800				81
91	91	1320	83 m.	C-22	1200	10 m.	C-31	930	6 hr.	C-31	700	900 s.	C-45	500	83 m.	C-51+				91
111b	111b	1325	33 m.	C-36	1160	90 s.	C-48	800	10's.	C-44	700	2½ hr.	C-50	480	10's.	C-60				111b
112b	112b	1315	1 hr.		1100	46 m.	C-49	890	1 hr.	C-43	750	26 m.	C-47	500	9 hr.	C-58				112b
135b	135b	1300	10's.	C-32	1120	30 s.	C-41	1010	40 s.	C-40	905	1 m.	C-39	630	10's.	C-50				135b
136	136																			136
160	160	1300	50 s.		1180	20 s.		860	22 hr.		600	10's.		500	33 m.					160
161	161																			161
162	162																			162
163	163	1290	500 s.		1200	4 m.		900	17 hr.		590	33 m.		500	80 m.					163
164	164	1300	83 m.		1200	6 m.		900	2.3 d.		600	100 m.		500	10's.					164
165	165	1260	10's.		1180	33 m.		850	7 d.		600	10's.		500	2.1 d.					165
168	168	1300	33 m.		1225	500 s.		880	31 hr.		560	87 m.		500	90 m.					168
169	169	1280	10's.		1200	10's.		850	7 d.		560	83 m.		490	10's.					169
Steels With Type IIIa Transformation Curves																				
75	75	1300	14 hr.	V-220	1250	1 hr.	V-269	1040	14 hr.	V-303	1010	14 hr.	V-310	875	2 m.	V-390	415	10's.	V-689	75
76	76	1300	15 hr.	C-15	1210	1.5 hr.	C-23	1150	3 hr.	C-26										76
81	81	1300	83 m.	V-264	1250	1 hr.	V-288	1090	10's.	V-362	970	10's.	V-383	870	200 s.	V-430	425	10's.	V-800	81
96	96	1280	10's.	C-21	1180	50 m.	C-26	1080	10's.	C-30	690	10's.	C-39	540	5 hr.	C-51	450	10's.	C-58	96
148	148	1295	10's.		1200	66 m.	C-21	1080	10's.	C-25	810	10's.	C-34	610	1 hr.	C-49	420	10's.	C-54+	148
166	166	1270	5.5 hr.		1175	83 m.		910	10's.		700	10's.		580	4 hr.		510	55 hr.		166
167	167	1230	5.5 hr.		1175	2.5 hr.		970	10's.		680	10's.		590	8.3 hr.		500	14 hr.		167
170	170	1265	5.5 hr.		1160	33 m.		920	10's.		680	10's.		560	5 hr.		500	6 hr.		170
171	171	1280	10's.		1175	100 m.		950	10's.		670	10's.		575	5.5 hr.		500	8.8 hr.		171
172	172	1270	2.3 d.		1150	2.5 hr.		960	10's.		660	10's.		580	8.3 hr.		500	4 hr.		172
Steels With Type IIIb Transformation Curves																				
27	27	1240	10's.	B-153	1200	2 hr.	B-163	1160	10's.	B-183	800	66 m.	B-293	700	350 s.	B-369	500	22 m.	B-408	27
28	28	1240	10's.	B-149	1200	10's.	B-153	1100	10's.	B-183	780	10's.	B-293	700	750 s.	B-388	500	2 hr.	B-429	28
46	46	1200	45 hr.		1090	8 hr.	C-4	1000	60 hr.		870	1 hr.		800	2 m.	C-31	700	14 m.	C-37	46
61	61	1250	10's.		1170	100 m.	C-19	1050	4.6 d.	C-19	950	10's.	C-28	875	5 m.	C-30	455	10's.	C-51+	61
66	66	1310	10's.	V-158	1250	66 m.	V-198	1060	10's.	V-273	1000	10's.	V-258	950	30 s.	V-300	500	10's.	V-563	66
89	89	1300	33 m.	C-4	1250	25 m.	C-7	1100	62 hr.	C-23	900	10's.	C-28	800	10's.	C-39	500	10's.	C-48+	89
90	90	1360	5 hr.		1225	14 m.	C-22	1150	35 m.											90
93a	93a	1275	10's.	C-8	1200	83 m.	C-12	1060	10's.	C-18	935	10's.	C-29	880	4 m.	C-30	540	10's.	C-44	93a
93b	93b	1260	10's.	C-4	1180	2.2 hr.	C-12	1065	10's.	C-20	920	10's.	C-30	835	85 s.	C-35	550	10's.	C-44	93b
94	94	1300	11 hr.		1250	5.5 hr.	C-7	1140	11 hr.		900	11 hr.	C-42	700	6 m.	C-47	500	10's.	C-52	94
95	95	1265	10's.		1200	10's.	C-15	1080	10's.	C-20	750	10's.	C-36	600	22 m.	C-48	400	10's.	C-56	95
102	102	1120	10's.		1100	9.3 d.	C-17	1080	10's.		900	10's.	C-31	800	700 s.	C-38	425	10's.		102
141	141	1240	10 hr.	C-11	1175	3.5 hr.		1100	8 hr.											141
142	142	1240	10's.		1170	2 hr.	C-18	1085	10's.	C-19	950	10's.	C-28	875	200 s.	C-30	455	10's.	C-51+	142
149	149	1290	8 hr.		1200	1 hr.	C-20	1100	8 hr.		800	8 hr.	C-33	600	30 m.	C-44	380	8 hr.	C-54	149
152	152	1280	10's.		1180	1 hr.	C-20	1000	10's.	C-29	720	10's.	C-39	595	2.2 hr.	C-48	570	10's.		152
Steels With Type IIIc Transformation Curves																				
65	65	1300	10's.	V-160	1250	33 m.	V-174	1100	8.3 hr.	V-206	900	50 s.	V-300	500	10's.	V-544				65
86	86	1300	12 m.	C-8	1200	200 s.	C-15	1000	83 m.	C-31	725	100 s.	C-39	540	10's.	C-50				86
88	88	1300	83 m.	C-6	1260	10's.	C-12	1000	3.6 hr.	C-35	800	100 s.	C-38	525	10's.	C-48+				88
92	92	1300	20 m.	C-14	1250	10's.	C-27	1000	2.2 hr.	C-38	800	350 s.	C-40	400	10's.					92
140	140	1200	5.5 hr.		1000	6.4 d.	V-700	800	200 s.	V-345										140
145	145				1175	12 m.	V-248	1050	3.3 hr.		800	1 m.	V-342							145



ITEM	AUSTEN- IZED AT	GRAIN SIZE	AE ₁	AE ₁ IF*, AC ₁	S ₁		S ₂		S ₃		S ₄		S ₅		S ₆		M _s	ITEM		
					°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME				
Steels With Type IV Transformation Curves																				
49	1500	6-7			1245	2 hr.	1125	4.5 m.	1000	5 hr.								49		
116	1600†				1350	1345	10's.	1260	1 m.	820	10's.								116	
120	2190				1450	1400	40 m.	1225	1 m.	810	10's.								120	
124						1450	10's.	1310	4 m.	850	10's.	430	10's.	350	10 s.	155	2 s.		124	
126						1450	10's.	1320	4 m.	940	10's.	410	10's.	290	2 s.				126	
127	1600				1490*	1470	1 hr.	1350	2.1 m.	1260	4 m.								127	
128	1600				1500	1490	15 hr.	1375	2.5 m.	1250	5 m.								128	
176	1850				1535	1480	2 hr.	1400	15 m.	1140	45 hr.	650	20 hr.	530	1 m.				176	
176x	1830					1450	10 hr.	1360	7.8 m.	1140	400 m.								176x	
182	2100					1390	1 hr.	1310	12 m.	1200	1 hr.								182	
190	2460	7-9	1400		1650	0.5 hr.	1470	0.1 m.	1010	50 hr.							190			
191	2460				1580	4 hr.	1440	1 hr.	1185	25 hr.								191		
192	2460				1515	5 hr.	1430	3 hr.	1240	25 hr.								192		
Steels With Type IVa Transformation Curves																				
48		7-9	1400		1310	10's.	1150	50 m.	950	10's.	850	10's.	600	1 m.			48			
55					1330	1 hr.	1260	500 s.	1150	10's.	1050	10's.	950	10 s.				55		
105x	1650				1210	1250	10's.	1140	18 m.	1015	10's.	940	10's.	740	25 s.				105x	
106						1310	10's.	1150	1 hr.	950	10's.	850	10's.	600	1 m.				106	
114						1450	1 hr.	1325	4 m.	1160	1 hr.								114	
117	2190	7-8	1540		1420	1400	90 s.	1230	40 s.	800	10's.	750	10's.	680	30 m.	400	10's.	117		
118	2190				1440	1400	100 s.	1200	20 s.	820	10's.	700	10's.	650	1 hr.	320	10's.		118	
123	1800				1500	2 hr.	1340	55 s.	1150	30 m.									123	
129	1650				1475*	1450	15 m.	1325	26 m.	1200	4 m.								129	
130	1650				1480	1500	10's.	1360	1 m.	1025	10's.	860	10's.	715	0.5 s.				130	
Steels With Type IVb Transformation Curves																				
105	1560	7	1465		1290	3.5 d.	1200	83 m.	1050	10's.	950	10's.	705	5 m.	660	22 m.	550	10's.	105	
105†	1560				1275	10's.	1200	30 m.	1100	10's.	990	10's.	760	2 m.	680	4 m.	550	10's.	105†	
115	1700†				1375	1360	10's.	1230	350 s.	1025	10's.	930	10's.	800	35 s.	650	1 m.	620	10's.	115
175	1850				1460*	1420	1 hr.	1300	7 m.	1100	6 hr.	700	10 hr.	630	15 m.	400	5 hr.	320	10's.	175
180	2275				1610*			1500	800 s.	1100	10's.	700	10's.	550	33 m.	400	10's.	200	10's.	180
181	2250					1500	45 m.	1390	20 m.	1200	6 hr.	650	3 hr.	530	25 m.	400	3 hr.	370	10's.	181
183	2200				1520*	1500	2 hr.	1400	20 m.	1200	10 hr.	640	10 hr.	560	10 m.	400	20 m.	350	10's.	183
184	2350				1525*	1510	10 m.	1460	3 m.	1200	10 hr.	680	10 hr.	540	5 m.	400	21 m.	350	10's.	184
185	1650				1545	1530	15 hr.	1400	1 m.	1325	5 m.									185

ITEM	AUSTEN- IZED AT	AE ₁ IF*, AC ₁	S ₁		S ₂		S ₃		S ₄		S ₅		S ₆		M _s	ITEM
			°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME	°F.	TIME		
Steels With Type V Transformation Curves																
119	2190	1350	1400	10's.	1200	1 m.	670	10's.	615	7 d.	570	16.6 hr.	340	10's.		119
121	1600	1490*	1475	15 hr.	1380	2.8 m.	1250	30 m.								121
122	1800	1490	1450	20 hr.	1310	4.5 m.	1090	20 hr.	690	20 hr.	580	50 m.	440	1.5 hr.	420	122
125	1800		1470	1 hr.	1300	2.9 m.	1200	5 m.								125
177	2225	1520*	1490	35 m.	1400	18 m.	1200	6 hr.	620	2 hr.	550	28 m.	400	3 hr.	350	177
178	2235		1400	0.8 hr.	1330	0.46 hr.	1140	30 hr.	700	30 hr.	560	0.15 hr.	420	0.3 hr.	420	178
179	1625		1500	15 hr.	1375	4.5 m.	1210	4 hr.								179
186	2350	1545*	1520	20 m.	1440	9 m.	1180	20 hr.	650	1 hr.	600	4.5 m.	400	1.5 hr.	375	186
187	2235		1410	0.6 hr.	1340	0.5 hr.	1140	30 hr.	695	30 hr.	460	0.12 hr.	430	0.15 hr.	430	187
188		1360	1250	30 s.	1025	2 s.	700	20 s.								188
189		1360	1250	30 s.	1025	1.5 s.	650	10 s.								189

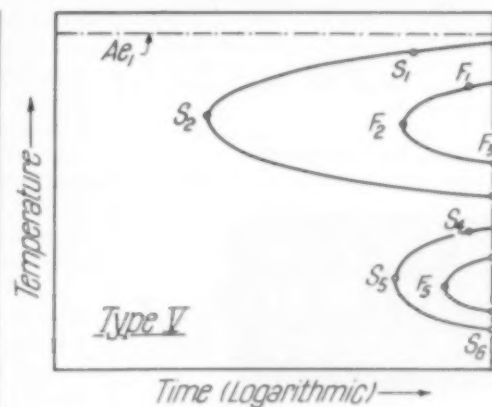


Footnotes to Tables:

- *These temperatures are for A_{c1} .
- †Probably too low to dissolve all carbides.
- ‡After overheating at 2200° F.
- ★Additional points on completion curve at 260° and 10°s., and 100° and 1 m. (hardness C-65).
- (a) Additional points on completion curve at 570° and 7 d., and 430° and 10°s.
- (b) Transformation completed below room temperature.

M.	ITEM	F ₁			F ₂			F ₃			F ₄			F ₅			F ₆			ITEM
		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
Steels With Type IV Transformation Curves																				
	49	1225	8 hr.	C-31	1160	1.5 hr.	C-20	1085	15 hr.	C-31										49
	116	1320	10's.		1250	200 s.	C-34	1030	10's.	C-38										116
	120	1400	10 hr.		1265	25 m.		950	10's.											120
	124	1445	10's.		1280	1 hr.		990	10's.		270	10's.		155	10 s.					124
	126	1420	10's.		1000	10's.		270	10's.		155	10 s.								126
	127	1405	5 hr.	C-12	1315	29 m.	C-15	1260	40 m.											127
	128	1400	3 hr.	C-16	1330	22 m.	C-20	1250	3 hr.	C-22										128
	176	1440	10 hr.		1390	3 hr.	C-9	1330	30 hr.		390	45 hr.		200	25 s.					176
770	176x	1400	400 m.		1300	2 hr.		1200	10 hr.											176x
200	182	1500	30 hr.	C-23	1350	10 hr.	C-28													182
	190	1650	25 hr.		1470	2 hr.		1100	100 hr.											190
	191																			191
	192																			192
Steels With Type IVa Transformation Curves																				
	48	1200	10's.		1120	14 hr.		1030	10's.		750	10's.		630	11 hr.		470	10's.		48
	55	1330	10's.		1250	5.5 hr.		1150	10's.		900	10's.		750	110 s.		600	500 s.		55
740	105x	1175	3.5 d.		1110	10's.	C-4	1035	4.5 d.											105x
	106	1200	10's.		1120	14 hr.		1030	10's.		750	10's.		630	70 hr.		470	10's.		106
	114	1380	8 hr.		1300	35 m.	C-20	1200	4 hr.	C-26										114
	117	1350	10's.		900	10's.		610	10's.		580	24 hr.		345	10's.					117
	118	1350	10's.		1240	3 m.		880	10's.		500	10's.		440	23 d.		350	10's.		118
	123	1445	20 hr.	B-75	1340	1.5 hr.	B-78	1150	15 hr.	B-82										123
	129	1445	15 hr.		1325	18 m.	B-77	1200	1.5 hr.	B-85										129
	130	1450	10's.	C-(-6)	1350	40 m.	C-6	1125	10's.	C-10	790	10's.		700	5 m.	C-39	600	33 m.	C-40	130
Steels With Type IVb Transformation Curves																				
550	105	1255	10's.		1200	42 hr.		1170	10's.		795	10's.		715	66 m.		570	2 hr.		105
550	105†	1230	10's.		1200	65 hr.		1190	10's.		840	10's.		730	36 m.		570	2 hr.		105†
620	115	1370	10's.		1245	1 hr.	C-11	1170	10's.	C-18	730	10's.	C-44	620	66 m.	C-48	540	10's.		115
320	175	1360	45 hr.		1300	20 hr.		1220	45 hr.		Below Room Temperature.									175
200	180	1500	16.6 hr.		1400	4 hr.	C-24	1170	10's.	C-29	650	10's.	C-55	600	3.3 hr.	C-55	460	10's.	C-55*	180
370	181	1460	15 hr.		1400	5 hr.	C-25	1340	15 hr.											181
350	183	1450	15 hr.		1400	8 hr.	C-30	1360	10 hr.											183
350	184	1470	60 hr.		1380	30 hr.		1280	60 hr.											184
	185	1500	15 hr.	C-18	1390	14 m.	C-24	1330	30 m.	C-27										185

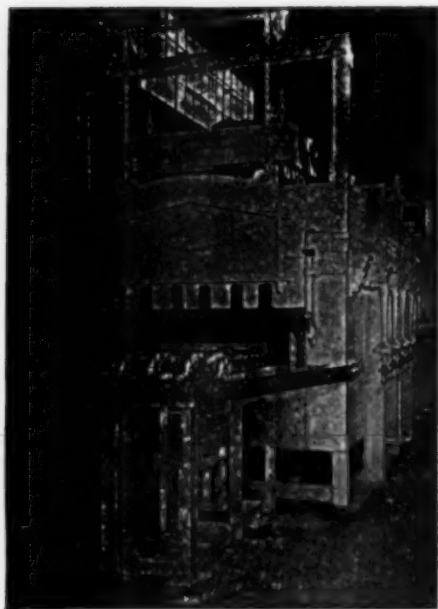
M.	ITEM	F ₁			F ₂			F ₃			NOTES
		°F.	TIME	HARD.	°F.	TIME	HARD.	°F.	TIME	HARD.	
		Type V									
	119	1400	10°s.	C-15	1260	12 m.	C-17	900			(a)
	121	1425	1 hr.		1380	20 hr.		1340	30 m.	C-21	
20	122	1400	45 hr.		1300	8 hr.		C-24	1200	45 hr.	
	125	1400	1 hr.	B-90	1325	44 m.	C-14	1200	1 hr.	C-21	
50	177	1440	8 hr.		1400	5 hr.	C-25	1350	8 hr.		
20	178	1350	15 hr.		1320	12 hr.		1280	30 hr.		(b)
	179	1465	15 hr.	1400	3.5 hr.	C-17	1300	13 hr.	C-20		
75	186	1440	20 hr.	1400	7 hr.		1350	20 hr.			
30	187	1360	8 hr.		1280	30 hr.					
	188	1220	100 s.		1025	13 s.		770	100 s.		
	189	1220	100 s.		1050	9 s.		700	100 s.		



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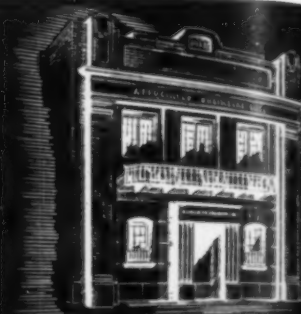
(Continued from page 814)

radio has any bearing on the matter, for vacuum tubes are now universally used — as far as I know — for broadcasting because of the stability of their current-producing characteristics and simplicity of design.

Stability of electrical characteristics has a real meaning to metallurgists using high frequency current. One of the main reasons why induction heating has gained its prominent place in the heat treating field today has been its ability to duplicate, with unskilled help, time and time again, piece by piece, results that are desired. This uniformity of product has been brought about only by the ability to eliminate all variables from the factors which make up the total heat transfer, namely, ampere-turns, the work coil, time, coupling distance between work and coil, and lastly, but by far not the least, frequency. It is obvious that if any of these factors is a variable, the result will be a variable, and a non-uniform product will result. Since the tolerances of this variation do not manifest themselves as clearly in some applications as in others, the spark-gap equipment has found, and rightly so, good use in many fields involving long heating cycles, and results of less precision, such as in the brazing and melting of metal where, should the heating cycle go 20% one way or the other, no harm is done. However, this requires manual observation of the piece during the heating cycle, in order to insure that the proper end point is reached.

Where precise heat treating is called for, or brazing applications in which localized heat is essential and unskilled operators must be employed to make the process feasible from an economical standpoint, we can take no chances that frequency may drift during the cycle. Here the electronic type equipment comes to the fore, since the vacuum tube oscillator is a fixed frequency device, governed by the values of the capacitance and inductance of the so-called "tank circuit".

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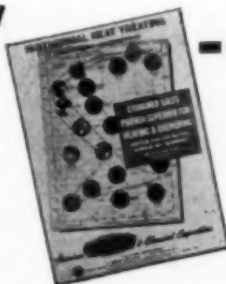
AMERICAN CYANAMID & CHEMICAL CORPORATION
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Please send my free copy of your new 16-page manual, ISOTHERMAL HEAT TREATING.

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of the new handbook,
ISOTHERMAL HEAT
TREATING, AUSTEMPERING,
MARTEMPERING,
containing a complete
reference to all published
"S" and "TTT" Curves for
107 AISI and SAE steels.



Nomogram for Calculating Hardenability

By Charles K. Donoho
and William W. McCulloch

Example is worked out for 4140. First ray is drawn between scales 1 and 2

(carbon and grain size); intersection with scale 3 is end of ray

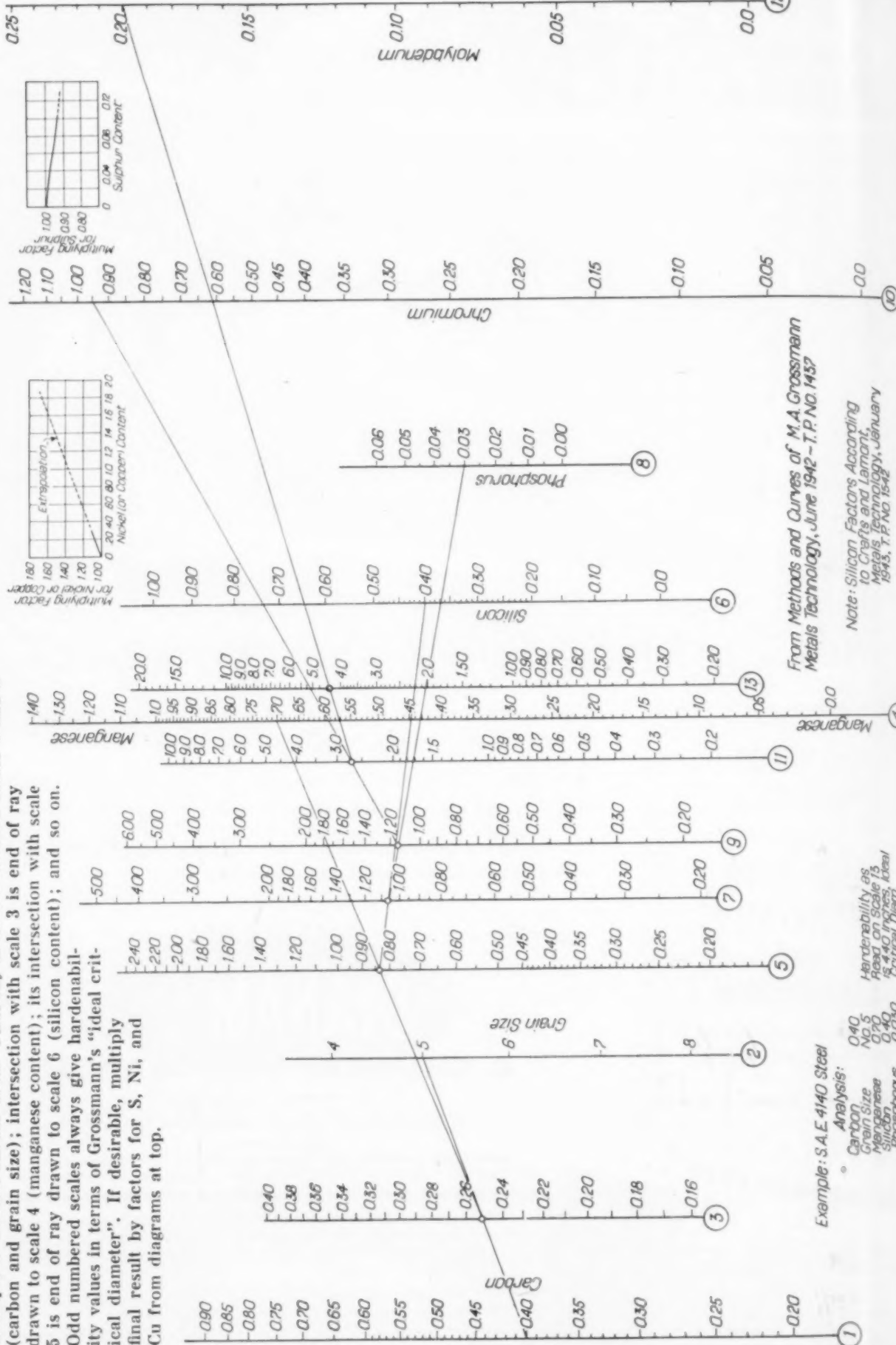
drawn to scale 4 (manganese content); its intersection with scale

5 is end of ray drawn to scale 6 (silicon content); and so on.

Odd numbered scales always give hardenability values in terms of Grossmann's "ideal critical diameter". If desirable, multiply

final result by factors for S, Ni, and

Cu from diagrams at top.



From Methods and Curves of M.A. Grossmann
Metals Technology, June 1942 - I.P. No. 1437

Note: Silicon Factors According
to Crafts and Laimant,
Metals Technology, January
1943, I.P. No. 1542

Example: SAE 4140 Steel

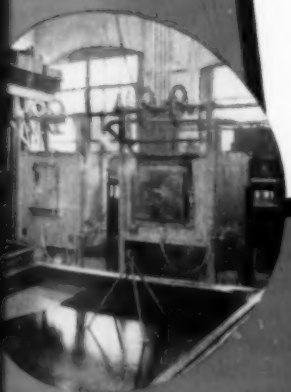
Analysis:
Carbon 0.40
Grain Size No. 5
Manganese 0.80
Silicon 0.30
Phosphorus 0.01
Chromium 0.00
Molybdenum 0.00

Hardenability as
Read on Scale 15
is 440 inches, Ideal
Critical Diameter

Low-Quality is going to really Count!

Quality and durability are becoming a "must" in postwar competition among all industries. One way to achieve this is through the Heat Treating Process. Not only does heat treating add infinitely to the quality and strength of high-grade metals, but it also renders inferior metals satisfactory for new, economical uses. The Heat Treating Specialists on the right can give you prompt, satisfactory service in . . . Annealing, Carburizing, Cyaniding, Hardening, Nitriding, Normalizing, Straightening, Stress Relieving, Tempering or Induction Hardening.

Investigate the possibilities of these processes in application to your product. Call one of these specialists and find out how heat treating can benefit your post-war production.



BOSTON

New England Metallurgical Corp.
9 ALGER STREET
SOUTH BOSTON 3313

CINCINNATI

The Queen City Steel Treating Co.
2978 SPRING GROVE AVE.
KIRBY 6300

CLEVELAND

The Lakeside Steel Improvement Co.
5418 LAKESIDE AVE.
HENDERSON 9100

DETROIT

Commercial Steel Treating Corp.
6100 TIREMAN AVE.
TYLER 6-6086

Commonwealth Industries
5922 COMMONWEALTH AVE.
MADISON 0573

Starr Heat Treating Company
10420 HARPER AVE.
PLAZA 8312

ELIZABETH, N.J.

American Metal Treatment Co.
ELIZABETH 2-2121

INDIANAPOLIS

Metallurgical Service Company
1020 E. MICHIGAN ST.
CHERRY 5203

LOUISVILLE

Louisville Metal Treating Service
314 WEST BLOOM STREET
MAGNOLIA 3674

MILWAUKEE

Thurner Heat Treating Company
809 WEST NATIONAL AVE.
MITCHELL 6360

NEWARK, N.J.

B-M Heat Treating Co.
220-222 CLIFFORD STREET
MARKET 3-6400
N.Y. City, RECTOR 2-2732

NEW YORK

Fred Heinzelman & Sons
154 SPRING STREET
WALKER 5-0720
Alfred Heller Heat Treating Co.
379-391 PEARL STREET
BEEKMAN 3-4534-5

PHILADELPHIA

Lorenz & Son, Inc.
1500 FRONT STREET
REGENT 7722 EAST 8255
Metlab Company
(Metallurgical Labs., Inc.)
1000 E. MERMAID LANE
CHESTNUT HILL 3500
J. W. Rex Company
LANSDALE, PA.
LANSDALE 4611
Wiedemann Machine Co.
1801-31 SEDGLEY AVE.
SAGAMORE 3027—PARK 2258

PITTSBURGH

Duff-Norton Manufacturing Co.
P.O. Box 1889, LINDEN 1156
Pittsburgh Commercial Heat
Treating Co.
49th St. & A.V.R.R.
SCHENLEY 6277

WORCESTER, MASS.

Greenman Steel Treating Co.
284 GROVE STREET
WORCESTER 4-1725

Personals

R. A. LEWIS ☉ is retiring as general manager of the Bethlehem plant of Bethlehem Steel Co., and will continue in consulting and advisory capacity. J. M. SYLVESTER ☉ has been appointed general manager, while A. D. SHANKLAND ☉, engineer of tests, will succeed Mr. Sylvester as assistant general manager of the Bethlehem plant.

Dr. TAYLOR LYMAN ☉, formerly metallurgist for Bendix Products Division of Bendix Aviation Corp., South Bend, Ind., has been appointed editor of the ☉ Metals Handbook and secretary of the Handbook Committee; he will also serve as editor of the Buyers' Guide and Data Book published by the Society.

JOSEPH T. SULLIVAN ☉ has been appointed as technical sales representative for MacDermid Inc. of Waterbury, Conn.

ROBERT S. ROSE ☉ has been appointed district sales manager of the new office opened by Latrobe Electric Steel Co. in Boston, Mass., covering eastern Massachusetts, Rhode Island, New Hampshire and Maine.

HERBERT J. FRENCH, past president ☉, has resigned as assistant director for raw materials and facilities of the Steel Division, War Production Board, Washington, D. C., and has resumed his duties as assistant manager of the development and research division of the International Nickel Co., New York.

Promoted by Bethlehem Steel Co.: J. H. STOLL ☉ from assistant engineer of tests to engineer of tests; T. G. FOULKES ☉ to assistant engineer of tests.

C. S. HEGEL ☉, special steel representative for Joseph T. Ryerson & Son, Inc., has been appointed manager of the special steels department in Chicago.

HOWARD A. BLANK ☉, a recent graduate of Lehigh University, has been appointed to the staff of Battelle Institute, Columbus, Ohio, where he will be engaged in research in foundry metallurgy.

ORLO E. BROWN, JR. ☉, former chief engineer of the Virginia Lincoln Corp., has been made plant superintendent of the White Heat Treating Co., Huntington Park, Calif.

WILLIAM L. RUDIN ☉, formerly with Universal Castings Corp., now research metallurgical engineer for G & W Electric Special Co., Chicago.

GENE K. McDOWELL ☉, a recent graduate of the Missouri School of Mines, has been appointed to the staff of Battelle Memorial Institute, Columbus, Ohio, and assigned to the division of research in non-ferrous metallurgy.


ARDEN L. KNIGHT ☉ has returned to Braeburn Alloy Steel Corp. as Eastern New England sales manager after three and a half years' service in the U. S. Navy.

M. M. ALLISON ☉, formerly heat treat foreman at Allison Div., General Motors Corp., Indianapolis, now with Wheelock, Lovejoy & Co. at the Detroit warehouse.

Clean, Reliable, Economical TOOL HARDENING The SENTRY way

Say, George —
What's this about
Sentry Diamond Block
controlled atmospheric
high speed steel hardening?

Well, Ed —
I've used Diamond
Blocks and Sentry
Furnaces for years.
You just can't beat
that combination!




SENTRY Diamond Blocks produce uniform, maximum hardness without scale or decarburization on all types of high-speed and high carbon, high chrome alloy steels. Work is clean; close tolerances maintained. Furnace may be operated with perfect results by the youngest apprentice.

Used by leading industrial companies. Economical — clean — quick heating — correct hardness — no decarburization — sizes and capacities to fit your needs.


Investigate! Write for bulletin 1020-6A3.

**SENTRY MODEL "Y"
ELECTRIC FURNACE**



The Sentry Company

FOXBORO, MASS., U. S. A.



M. L. FREY ☉, formerly chief metallurgist of the Aircraft Engine Division, Packard Motor Car Co., now assistant to the general works manager, Tractor Division, Allis-Chalmers Mfg. Co., Milwaukee.

A. S. HENDERSON ☉ has been appointed professor of metallurgy at the New Mexico School of Mines and will act as consultant for the New Mexico Bureau of Mines and Mineral Resources.

W. H. SPARROW ☉, formerly metallurgist, materials laboratory, Berry Gyroscope Co., Brooklyn, N. Y., is now metallurgical engineer, materials engineering department, Westinghouse Electric Corp., East Pittsburgh, Pa.

OSCAR E. SWENSON ☉, formerly research engineer with Metal and Thermite Corp., has now returned to Chicago Steel & Wire Co., in charge of research and development of arc welding electrodes.

PAUL K. ZIMMERMAN ☉, formerly metallurgist with Globe Steel Tubes Co., is now associated with the special steels division of Jos. T. Iverson & Son, Inc., Chicago.

Transferred by General Electric Co.: WALTER L. FLEISCHMANN ☉, formerly from the Ft. Wayne Works laboratory to the turbine generator engineering division at Schenectady.

FOSTER R. WOODWARD ☉, formerly chief research engineer for Federal Machine and Welder Co., Warren, Ohio, is now application engineer for Progressive Welder Co., Detroit.

JAMES F. BARNES ☉, formerly in the New York district sales office of Carnegie-Illinois Steel Corp., has been appointed midwestern sales representative for Barrett Div. of Allied Chemical and Dye Corp., with headquarters in Cleveland.

THOMAS L. PIKE ☉, formerly chief inspector for Studebaker Corp., is now employed by Grand Rapids Brass Co., as a sales representative.

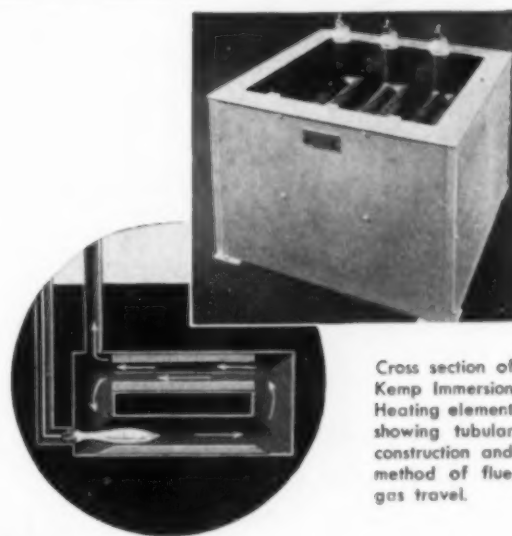
JOHN ALICO ☉ has resigned his position as supervising field engineer for Hydropress, Inc. and is now a member of the engineering staff of Singmaster & Breyer, consulting metallurgists and engineers in New York.

H. LeROY WHITNEY ☉, formerly technical consultant to War Production Board Chairman Donald M. Nelson, has been elected chairman of the board, Intercontinental Distributors, Inc. of New York and Washington, D. C.

BERNARD R. QUENEAU ☉, senior metallurgist at the U. S. Naval Proving Ground, Dahlgren, Va., and recently returned from the Naval Technical Mission in Europe, has been promoted to Commander U.S.N.R.

STANLEY P. WATKINS ☉, manager of the sales engineering department and head of the sales development department at Rustless Iron and Steel Corp., Baltimore, has been appointed manager of the market development division.

WM. W. AUSTIN, JR. ☉, formerly with Consolidated Vultee Aircraft Corp. in Nashville, Tenn., has accepted a position as research metallurgist on the staff of Southern Research Institute, Birmingham, Alabama.



Cross section of Kemp Immersion Heating element showing tubular construction and method of flue gas travel.

KEMP IMMERSION MELTING

*Heating Units are Inside the Metals Heated
thus Effecting a 40% Saving in Fuel.*

Blanket of exhaust gases over molten metal surfaces minimizes dross formation. This operation combined with KEMP close temperature control greatly increases efficiency and prevents waste.

These Immersion Melting units are adaptable for the following purposes: melting of all soft metals, lead, tin, pewter and solder—the heating of compounds, stereotyping and electrotyping—lead baths for annealing and tempering—tin coating, lead coating and battery grid casting.

A Special Bulletin E 200.1 has been prepared giving most complete information. Complimentary copy will be forwarded upon request.

★

Numerous Other Kemp Products Include:

ATMOS GAS PRODUCERS, NITROGEN GENERATORS, FLAME ARRESTORS, INERT GAS PRODUCERS, DYNAMIC DRYERS, INDUSTRIAL CARBURETORS, INDUSTRIAL BURNERS, FIRE CHECKS, STEREOTYPE POTS.

★

The C. M. KEMP Manufacturing Co.

405 E. OLIVER ST.

BALTIMORE 2, MD.

SO HE WENT HOME WITH A
LABORATORY LECTRODRYER
"UNDER HIS ARM"



A true story of a man who came to Lectrodryer for DRYing help.

A supersecret device required super-drying in its production. The manufacturer came to Lectrodryer with his problem—

"What kind of drying machine do we need? How many air changes will be needed to produce that dryness? What air agitation will be required?" And then came the \$64 question: "How soon can we get the Lectrodryer that will do that job?"

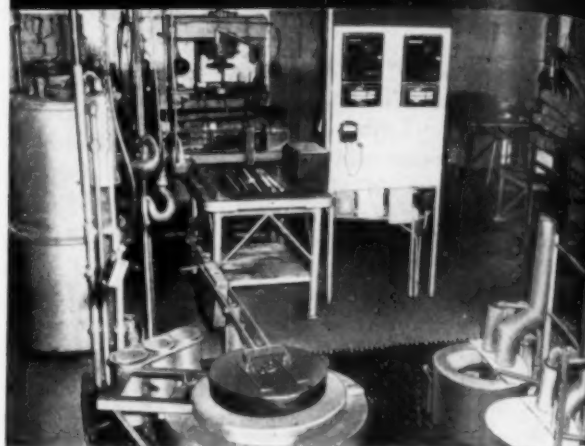
Today, that plant is actually in limited production with the help of a Laboratory Lectrodryer. The production-size machine is being built.

Lectrodryer welcomes men with DRYing problems. For such help, write PITTSBURGH LECTRODRYER CORPORATION, 317 32nd Street, Pittsburgh 30, Pennsylvania.

LECTRODRYERS DRY WITH ACTIVATED ALUMINAS

PITTSBURGH
LECTRODRYER
CORPORATION

IN HOLLYWOOD



Wheelco controls help solve broach hardening problems

From coast to coast you'll find Wheelco instruments (more than 30,000 installed since January 1943) helping industry solve problems involving temperature control and combustion safeguard. In California, for example, Wheelco "Electronic Control Principle" Potentiostats are used to secure precise temperature conditions on furnaces used for heat treat-

ing broaches in the plant of Hollywood Heat Treating Company.

Wheelco controls were chosen because of their high accuracy, speed of operation, and dependability. Do you have a postwar problem involving temperature control or combustion safeguard? Our engineers will be glad to work with you.



The WHEELCO complete line includes Flame-control combustion safeguard . . . Capacitrol pyrometer controllers . . . Indicating pyrometers . . . Proportioning controls . . . Program controls . . . and a wide range of accessories.

Ask for Condensed Catalog Z6300, detailing the complete line of Wheelco instruments and accessories.

The instrument shown below is a Wheelco Universal Type Capacitrol, available as 2-position, 3-position or proportioning type of control.



WHEELCO
INSTRUMENTS COMPANY

835 W. Harrison St. Chicago 7, Ill.

WHEELCO

Personals

EARNshaw COOK is retiring Jan. 1 as chief metallurgist of the American Brake Shoe Co., Elizabeth, N. J., but will continue in consulting capacity with the company and will engage in a limited amount of general consulting work. RAYMOND H. SCHAEFER will be promoted from assistant to chief metallurgist for American Brake Shoe Co.

E. S. HARRAR, formerly engineering manager, Louisville plant, Curtiss-Wright Corp., is now professor of wood technology at Duke University, Durham, N. C.

RALPH N. SCHAPER has resigned as plant manager of Fort Pitt Steel Castings Co., McKeesport, Pa., to become assistant general manager of operations at Westlec-ric Castings, Inc., Los Angeles.

JOHN F. ECKEL, formerly on the faculty of Purdue University, is now associated with General Electric Co. in Schenectady as a research metallurgist.

H. A. SOSNIN, formerly welding engineer in the research and development department of Tube Turns, is now with Stanley G. Flagge & Co. as promotion and development engineer.

Transferred by Latrobe Electric Steel Co.: H. EMERSON SPARKS, sales engineer, from New York to Philadelphia.

L. DIVELEY, formerly chief chemist for the aviation plant of Hudebaker Corp. at Ft. Wayne, Ind., is now with Cutler-Hammer as finishing engineer.

OTTO ZMESKAL has been appointed director of research of the Bridgeville division of Universal-Tylops Steel Corp.

B. J. BRUGGE has been appointed welding engineer and district manager of sales and service for the new branch sales office in St. Louis of the Lincoln Electric Co. of Cleveland.

FREDERICK COOPER, formerly with the Midvale Co., is now sales manager of Wilson Steel & Tool Co., Philadelphia.

MAMMOTH PRESS WILL TEAM UP with R-S FURNACES



Leading on the horizon—the largest die forging press in the world, now in process of installation at Wyman-Gordon. When this press is completed at the end of this year, it will make available larger magnesium and high strength aluminum alloy forgings than any yet made will be available. This press will be operated by Wyman-Gordon Products Corporation, a wholly owned subsidiary of Wyman-Gordon Company for the purpose of Reconstruction Finance Corporation which

owns the press, and will be available to furnish magnesian in particular and to industry generally for expansion in and for the development and production of light metal forgings. This means to our country reduced weight which, in turn, means increased payload and greater performance for American planes. . . And for industry in general—complete range of magnesium and aluminum forgings.

WYMAN-GORDON
PRODUCTS CORPORATION
WORCESTER, MASSACHUSETTS, U. S. A.



The largest die forging press in the world, recently announced by Wyman-Gordon Products Corporation, "will make available larger magnesium and high strength aluminum alloy forgings than any yet made."

Wyman-Gordon Products Corporation selected these types of R-S Furnaces for the heat-treatment of work to be turned out by this press.

3 R-S Continuous Convection Type Forging Furnaces

1 R-S Convection Type Heat-Treating and Aging Furnace

This is another instance of selection due to R-S high-quality construction coupled with R-S designing ingenuity and dependable performance.

R-S Furnaces of Distinction

FURNACE DIVISION
R-S PRODUCTS CORPORATION

128 Berkley Street

Philadelphia 44, Pa.

Production Increased 5000% in This TRENT Electric Salt Bath Furnace

This TRENT Salt Bath Furnace increased production from 2 to 110 pieces per hour in brazing Monel strip to copper tubing . . . an operation that results in making sea water drinkable in *unlimited quantities*. The bi-metal construction makes the tubing, used for sea water stills, *self-descaling*, eliminating their frequent dismantling for removal of salt scale.

Self-descaling is accomplished by intermittent heating-cooling of the tubes, resulting in a *flexing* action that throws off the scale, permitting continuous distillation. The furnace illustrated measures 12" wide, 24" deep and 88" long, inside the pot. It is rated at 70 KW. on 230 Volts. Uniform temperature is assured by TRENT patented "FOLDED-AND-FORMED" heating elements, unequalled for efficiency and durability.



TRENT ELECTRIC SALT BATH FURNACES

are made in a variety of types and sizes, to meet every heat treating and capacity requirement. The one described below is typical in its assurance of efficient, economical operation.



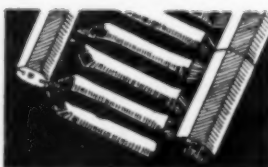
Write for complete Details on These and Other TRENT Electric Furnaces and Heating Elements.

TYPE PF SALT BATH FURNACE:

Temperature range, 1100° F. to 1700° F. Rigid, durable construction, with sturdy split type cover. Full range of sizes. Equipped with Trent Patented "Folded-and-Formed" Heating Elements. 17 KW., 110 Volts, Single Phase.

"Folded-and-Formed" Heating Elements

TRENT patented construction, providing numerous advantages over other types . . . low watt dissipation; uniform heat distribution and flexibility of control; wide temperature range (300° F. to 2000° F.); ease of installation; minimum maintenance cost.



TRENT Pat. "F-and-F" Ribbon Type Unit

FURNACES • OVENS • HEATING ELEMENTS
LAB and SPECIAL EQUIPMENT • KETTLES

Electrically Heated Industrial Equipment

HAROLD E. TRENT COMPANY

245 LEVERINGTON AVE., PHILADELPHIA 27, PA.

Pre-Treatment of Nitriding Steels

AFTER preliminary tests had shown that the hardness of the nitrided case of a Cr-Mo-V steel was affected by the prior heat treatment, five steels were examined:

No.	C	Cr	Mo	Other
1	0.37	1.23	0.69	
2	0.38	1.90	0.30	0.18% V
3	0.27	2.96	0.52	
4	0.18	3.10	0.53	
5	0.27	1.62	0.31	0.86% Al

Steels No. 1 and 4 had about the same maximum case hardness if the treatment prior to nitriding was (a) normalizing, (b) normalizing and quenching or (c) normalizing, quenching and tempering at 930° F. The vanadium in No. 2 increased the maximum case hardness of specimens normalized from 1550 to 1750° F. over the hardness in the corresponding quenched or quenched and tempered condition. Raising the normalizing or quenching temperature increased the maximum hardness attained during subsequent nitriding; this was most marked for No. 2 — as much as 65 numbers on the diamond penetrator scale, as the temperature increased from 1550 to 2000° F.

The most pronounced change in the maximum case hardness of steels No. 1, 2, and 3 was the continuous decrease in hardness (about 200 D.P.H.) which occurred as the tempering temperature was raised from 930 to 1300° F. There was a direct relationship between the case hardness and the post-nitriding core hardness of the quenched and tempered chromium steels; the case hardness exceeded the core hardness by about 375, 425, and 575 D.P.H. for steels No. 1, 2, and 3. The vanadium in steel No. 2 did not exert any marked influence on the case hardness but did have a pronounced effect on the softening of the core during the nitriding of specimens previously tempered at 1040° F. or lower. The maximum hardness of steel No. 3 was not greatly affected by modifications in preliminary heat treatment or by core hardness.

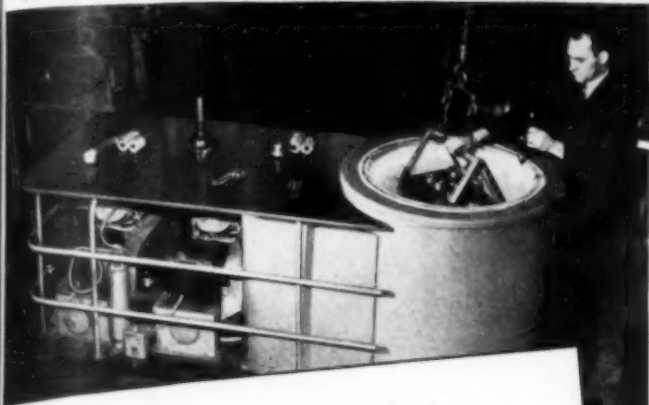
The main practical application of these studies would be the attainment of

(Continued on page 892)

★Abstracted from "A Note on the Relationship Between Preliminary Heat Treatment and Response to Nitriding of Some Nitriding Steels", by C. C. Hodgson and H. O. Waring, Iron and Steel Institute Advance Copy, Dec. 1941.

Average
100%
to 300%
Increase IN TOOL LIFE

Courtesy of
Electrical Production
Magazine



OHIO CRANKSHAFT INCORPORATED
2500 HARVARD AVENUE
CLEVELAND 1, OHIO

Mr. Rhodes Hanna
Industrial Equipment Division
Deepfreeze Corporation
703 Hanna Building
Cleveland, Ohio
Dear Mr. Hanna:

We are pleased to forward to you the results obtained
by deep freezing high speed steel tools through one of your
units. The results so far are very encouraging and we want
to thank you for your cooperation.

Tool	Operation	Type of Steel Worked	(Avg. For - Deepfreeze)	Per Grind	% of Increase
T-45008	Milling	SAE X-1335	371	968	160%
T-2007 (5/16-11")	Drilling	SAE 1080	5	14	190%
T-4696	Chucking	SAE 1045	1.0	1.5	50%
T-70261 (1-1/8")	Rough Tap	AMS 6415	30	490	300%
T-70262	Finish Tap	AMS 6415	29	86	140%
T-109	Finish Turn Head	AMS 6415	7	17	200%
T-4	Bore	AMS 6415	6	18	275%
T-40919 (1-1/2")	Rough Tap	AMS 6415	25	95	1000%
T-70261 (1-1/8")	Rough Tap	AMS 6415	30	340	10%
T-4533	Cheek & Fillet	Carbon Steel	12	15	120%
T-41692	Hub Spine on Front & Rear	AMS 6415	7	16	100%
T-12058	Hub 16-pitch thd Front & Rear	AMS 6415	70	200	80%
T-4416	Cheek & Fillet	SAE 1080	8	9	37%
T-20758	Flange	SAE X-1335	30	41	131%
T-412	Cut Woodruff Key	SAE 1080	70	162	180%
T-1067	Aircraft	OS-X-1050	60	143	210%
T-308	(1" Tap) Tap Detroit Steel Shaft	OS-X-1050	60	143	210%
	Hub 12-pitch thd in Univ. Line	OS-X-1050-1	30	124	210%
	Cumulative				

Very truly yours,
OHIO CRANKSHAFT, INC.

C. H. Scheibing
Chief Process Engineer

FREE COLD TREATING FACTS TO IMPROVE PRODUCTION...

You can use the information in this new Deepfreeze Booklet to improve many phases of your production. It relates a complete history of cold treating... details several of the most reliable cold treating procedures... cites actual performance stories that you can duplicate... and lists much additional data of extreme value. Write today for your free copy.



Deepfreeze Industrial Chilling Machine

Here is a manufacturer who has increased the life of standard high speed steel cutting tools on an average of from 100% to 300% through a simple sub-zero treatment in a Deepfreeze Industrial Chilling Machine. Shop records show gains up to 1000% per grind after tools have been subjected to cold treatment. The result of this increased tool efficiency is less machine down time and greater production economy.

Study the results that were obtained by this manufacturer and evaluate it to your own process. You, too, can secure equally good results by subjecting your tools to the same simple and inexpensive treatment in a Deepfreeze Industrial Chilling Machine.

Check the Results of Applying Cold Treating To Your Production by Contacting Deepfreeze Engineering Service

Cold treating is not confined to the treatment of metal cutting tools. It is used with the same efficiency for many component parts where long life and very close tolerances are required. The greater dimensional stability, possible by reason of the sub-zero treatment, will also prove highly profitable in critical components, gauges, and all types of precision instruments. It is being widely used to contract metal for shrink-fit assembly and for testing and numerous other purposes. All can be accomplished right in your own plant. Why not find out? You can pre-determine the many results of applying cold treating to your production by contacting Deepfreeze Engineering Service. This service will not obligate you in any way.

1. Molybdenum Type Steel Tools

- Use standard heat treatment and drawing procedure.
- Cool to room temperature.
- Cold treat at -120° F. to -130° F. for two hours and allow to return to room temperature.

2. Tungsten Type Steel Tools 18-4-4 and 18-4-2

- Use standard heat treatment and drawing procedure.
- Cool to room temperature.
- Cold treat at -120° F. to -130° F. for two hours and allow to return to room temperature.

RESULTS:

- Tool failure after cold treating almost disappeared.
- Magnaflux inspection showed very few cracks, seams, or other irregularities.
- Rockwell "C" hardness 63-65.
- Tool life greatly increased up to 1500%.

Detailed heat treating and drawing procedures used on these tools available upon request.

(Continued from page 890)

ment of higher nitrided hardnesses of chromium-molybdenum steels by using low tempering temperatures (where high impact strength is not essential). This increase in hardness is believed due to the fact that at the lower tempering temperatures less alloy is locked up in alloy carbides, thus leaving more available for nitride formation. The aluminum in the chromium-aluminum-molybdenum steel does not form carbides, and therefore is available for nitride formation regardless of the temperature. ☼

Rotary Furnaces*

TODAY there are over 200 rotary hearth furnace designs. A study of five basic applications indicates why they meet with such favor.

The pan-dumping rotary has an alloy hearth supported on a shaft extending up through the center. The hearth is made in hinged, tray-like sections so the material may be dumped into a quench tank. The furnaces may be designed with direct-fired oil burners, gas burners, radiant tubes or electric heat-

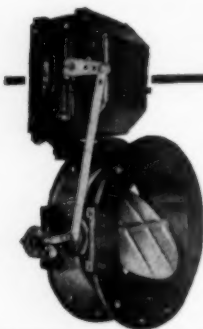
ing elements. Some parts will not quench properly from a standard chain belt conveyer hardening furnace but can be quenched uniformly from the pan-dumping rotary. This furnace is especially adaptable to the use of a protective atmosphere.

Another type handles miscellaneous plates and bars for forging plus some welded sections for annealing. Ordinarily the plates are charged and discharged by tongs, but with the rotary furnace automatic charging equipment has been developed which offers the simplest means of conveying thin sheets at 2200° F. Furthermore, a single door for both loading and unloading with the advantage of decreased heat loss can be used. If two men must work at loading and unloading or if the cold material must be kept away from the hot steel, two doors are preferable.

For annealing, the parts are generally loaded directly on an alloy plate hearth set on the refractory hearth. The alloy hearth requires frequent replacement and these furnaces are not as successful as the all-refractory-hearth forging types. Usually any protection offered by a water seal can be duplicated by a sand seal.

The rotary end-heating type of furnace can be illustrated by a unit used to heat odd shapes along with about half the length of long bars; therefore, the furnace had to have a continuous slot all the way around. The walls and dome were hung from an overhead framework. A circular rail, fastened to the bottom structure, was carried on stationary wheels. The flat hearth was held by a center bearing. The water-cooled beam forming the top of the slot supports the wall and prevents heat from feeding back along the bars. A seal had to be installed all the way around to prevent excessive scaling. Such a furnace is excellent for heating the ends of bars unless the bars are so long as to prevent installation of a seal. A further advancement involves the use of sealed radial muffles made of silicon carbide so the steel can be heated in a controlled atmosphere. A protective gas, consisting of 98% nitrogen, is fed into these muffles continuously, maintaining a slight positive pressure. The general construction of these furnaces is similar to the rotary end-heating

*Abstracted from "Developments in Rotary Hearth Furnaces", by J. H. Loux, *Iron and Steel Engineer*, July 1945, p. 52.

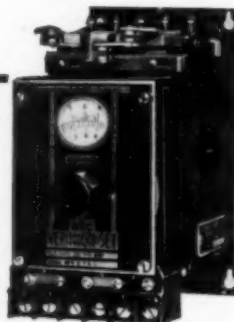


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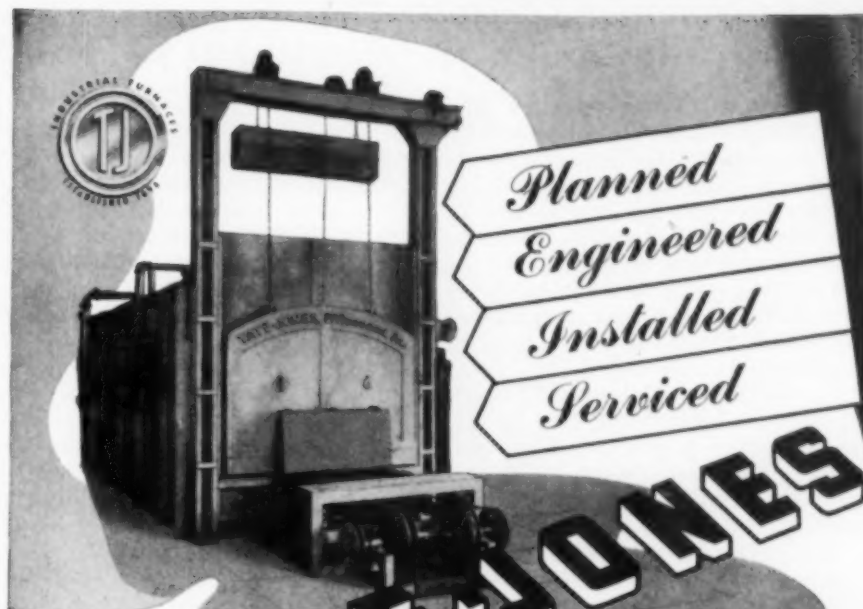
furnace, with walls, burners and furnace dome hung from an overhead framework.

The most common rotary hearth furnace is the doughnut type with a refractory hearth, used for heating prior to forging. Here, rotary furnaces have proved more uniform, faster and more efficient than the standard pusher type. The flanged wheel principle for maintaining the revolving hearth is not satisfactory. The use of a center bearing to pivot the entire hearth and allow the hearth to expand in all directions with no flanges on the wheels is much better. Standard drives for these units are the positive rack and pinion and the chain type. Some of the older rotary hearth furnaces were driven by a pusher rod or pawl type mechanism which required considerable maintenance. In later years, hydraulically operated drives have been used with much success.

The location of the burners as related to the steel, the furnace dome, or the size of the furnace is important. A load of 40 lb. per hr. per sq.ft. of hearth is a safe figure to determine the proper size of furnace. If the billets can be placed on end, this figure may be increased but the unit becomes more expensive to operate due to rapidly increasing maintenance and decreased efficiency.

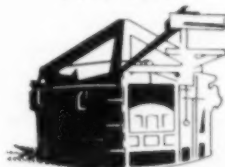
Sloping hearth roll-down furnaces have long been used for feeding hot billets to piercing mills. The installation of a large rotary furnace (40 tons per hr.) showed its greatest advantages to be decreased manpower, more uniform and controlled heating, a definite decrease in scale loss (2%) and the ability to set up and duplicate more precise heating cycles. The bottom is made in two separate frames with the framework supporting the wheels not fastened to the framework supporting the refractory hearth. There are spring loaded rollers on the inside diameter to keep the hearth centered. Costs have amply justified the installation of this furnace—the total saving on labor and scale loss is \$23,000 a month. No fuel economy is apparent because the older furnaces used recuperators whereas the rotary units do not.

The rotary has many advantages. It can be unloaded and loaded from one spot, it can maintain a proper atmosphere and pressure, and it is inherently self-emptying. However, simplicity of design and operation are most responsible for the success of the rotary furnace.



by

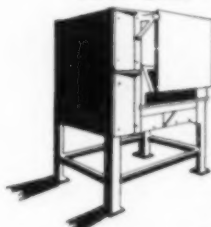
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The Acicular Constituent in Austempered Steels*

TRANSFORMATION of austenite at temperatures in the martensitic zone was investigated by a sensitive recording dilatometer, as well as with hardness measurements and microscopic examination. The present results differ mainly from the results previously published by others in the length of the induction period (time prior to the start of transformation), which was far shorter. This may be due to the use of relatively larger samples in the present work.

The shape of the S-curve is explained on the basis of Tammann's curve for the change of the velocity of crystallization with temperature. The reason for the extra node in the curves for certain alloy steels at around 900 to 1100° F. is believed due to the presence of an alloy carbide.

★Abstracted from "Some Observations on the Austempering and Isothermal Transformation of Steels, With Special Reference to the Production of Martensite", by F. C. Thompson and L. R. Stanton; Iron and Steel Institute Advance Copy, Nov. 1944.

In some steels there is a labile shower of acicular crystals of ferrite accompanied by a rapid transformation in a temperature range of 850 to 1025° F. Carbon is apparently retained in solid solution in this precipitated ferrite, because of its diminished ability to diffuse into the surrounding austenite at the temperature of formation. The term "ferronite" is suggested for this constituent.

There is small possibility that stress may depress the A_r point. It is believed, rather, the period of induction is caused by a gradual relaxation of the stresses set up by sudden cooling or by the volume change at the surface due to the formation of a skin of martensite. Further, the marked parallelism between the curve for the commencement of the transformation and that for its completion suggests that there is no true period of incubation, but that the rate of change is initially too slow to detect. Again, if the induction period is a period of stress relaxation it should be related to the creep strength, and

a comparison of the creep strength and the induction period at 850 to 925° F. for a number of steels shows that in general the higher creep strengths correspond to the longer induction periods.

The dilation curves taken during the cooling of a sample of steel consist generally of five stages: (a) A rapid expansion, due to the formation of the martensitic skin; (b) a stage of temporary equilibrium analogous to the induction period; (c) a second expansion, initially slow but increasing in velocity; (d) a limited stage with expansion rate proportional to the amount of unchanged austenite; and (e) a period of diminished rate of change, but still measurably greater than that which the first-order reaction, as in (d), would require.

The authors believe that nucleation does not play any considerable part in the formation of martensite, a process which they think bears a marked similarity to mechanical twinning. There is some experimental evidence that at low

(Continued on page 897)



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Acicular Phase

(Continued from page 894)

quenching temperatures tetragonal martensite may first be formed and then tempered almost at once to the cubic variety.

The tempering curve of a martensitic steel transformed isothermally differs radically from that of the same steel tempered after oil quenching or water quenching. In the former there is little or no evidence of the contraction between 200 and 400° F. due to the martensite inversion. The isothermal samples, therefore, are already in the cubic state. Further, the hardness of such steel, when subsequently retempered, is appreciably higher than that of the water quenched material similarly tempered. Therefore, the isothermal martensite is more stable than that of the water quenched steel, as would be expected if it were in a condition of much lower internal stress. The martensite needles also etch far more readily than tetragonal martensite.

There is strong evidence that grain size exerts a considerable effect on the A_{r1} point with the reactivity increasing with decreasing grain size. The $A_{r''}$ change, however, is apparently unaffected. The presence of troostite in the microstructure does not materially affect the steel's subsequent transformation in the bath. Samples with a sorbitic prior structure were most prone to react, those with a spheroidal structure were next, and those with a pearlitic structure were most sluggish. Therefore, apart from changes of composition, the two factors which more than any others affect the results of isothermal treatment are first, the degree of deoxidation and second, the existence of a prior sorbitic structure.

The difference in properties in a normally quenched from isothermally transformed steel is simple to explain for temperatures above $A_{r''}$, since the isothermally transformed material does not pass through the intensely stressed martensitic stage, thereby eliminating microcracks. Where martensite is formed in such samples, the difference may reasonably be assigned to the direct production of the cubic form. The low degree of internal stress in martensite formed isothermally is evidenced by its resistance to tempering. Therefore, although such martensite is originally softer than when quenched, it may be harder and tougher when tempered.

Salt Pot Corrosion*

CORROSION of steel salt bath pots by molten alkali nitrates was studied in six plants for over two years. These salt baths were used at 575 to 750° F., and 910 to 930° F., for heat treating aluminum alloys.

All the furnace settings were gas fired with certain main design features common to all. They were welded or bolted steel casings lined with firebrick and were fired along both sides with burners at intervals of about 1 in. There was a firebrick baffle between the burners and the pot. All had fitted sheet steel lids.

Arc welded mild steel or boiler steel pots of three types were used, either large rectangular pots made of flat sheets or medium sized pots with the side and bottom made of one formed sheet and with flat ends welded on. The ratio of depth to width was slightly over one for the large rectangular pots, and less than one for the medium sized pots.

The salts were basically eutectic mixtures of sodium and potassium nitrates except for one bath which contained up to 14% sodium nitrite instead of sodium nitrate.

Initially, daily analyses were made for chloride, nitrite and alkalinity. The nitrite determination was soon dropped as it appeared to give no useful information. The chloride did not change rapidly, so it was finally checked once a week to guard against high chloride salts.

The study indicated that with commercially available salt with a guaranteed maximum sodium chloride of 0.3%, the corrosion of boiler plate and mild steel was negligible at 700° F. and proceeded slowly at 925° F. Where a rapid attack took place, furnace design appeared to be a fairly prominent factor. Welded seams at the ends were not attacked preferentially. Shallow pots were more prone than deeper pots to hot spots, and this appeared to be a secondary factor in promoting corrosion. Additions of sodium nitrite did not postpone corrosion. The rate of increase of the alkalinity was an index of the rate of corrosion. Practically, the use of ingot iron pots was a complete insurance against corrosion.

*Abstracted from "Corrosion of Steel Salt-Bath Pots by Molten Alkali Nitrates", by R. J. Box and B. A. Middleton, Iron and Steel Institute Advance Copy, January 1945.



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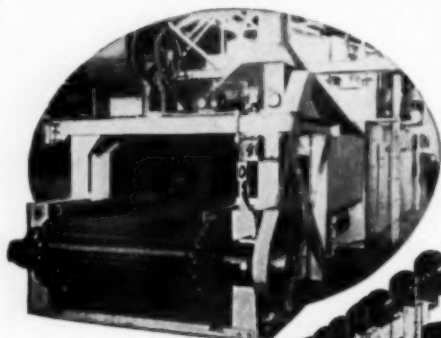
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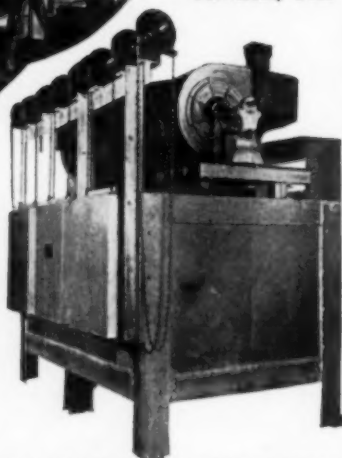
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By Malcolm F. Judkins
Chief Engineer, Carbide Division
Firth-Sterling Steel Co.
McKeesport, Pa.

The Cutting Tools of World War II

CUTTING TOOLS and their mechanical counterpart, machine tools, have emerged from the present conflict as our most potent weapon. This country has been known almost from colonial days as a manufacturing nation. We have long been acknowledged the world's masters of mass production. Early in the European struggle, before we formally entered the war, it was prophesied that when "Hitler put this war on wheels, he drove it right down our alley". The abundance and the quality of our tools provided our fighting forces with an overwhelming superiority in quality and quantity of all that equipment which the military man calls matériel. This fact made final victory less costly in lives.

War matériel is predominantly metallic. Implements of war are fashioned from hard, tough, wear resistant metals of relatively low machinability. Furthermore, the intricate mechanism of aircraft instruments, bomb sights, armament, munitions and combat vehicles requires precision machining to high quality surfaces and close tolerances. These are the requirements of the tasks that metallurgists, engineers, and machine tool builders discharged so well that final victory is now a reality.

High Speed Steels — When enemy forces conquered mining districts in various parts of the world, our supplies of critically needed alloys were seriously limited. Because of the lack of sufficient tungsten, recourse was made to high molybdenum types of high speed steel. From a variety of causes their efficiency was not all that could be desired, but they were greatly improved after restrictions on tungsten content were removed. Our alloy situation substantially

improved with the progress of the war. Molybdenum steels have certain rather well known advantages, such as low temperature heat treatment and relatively greater toughness than conventional 18-4-1 high speed for such applications as taps and other threading tools. They will continue to be used long after alloy shortages disappear.

One wartime development took the direction of increasing the cobalt content of tungsten high speed steels, resulting in a marked improvement in their ability to cut metal and heat treated steels in the hardness range from 300 to 400 Brinell, as well as hard cast iron and abrasive non-ferrous material.

Insistent demands for maximum output of war materials have forced the development of constantly improved methods of heat treatment of high speed steels. Salt bath hardening has been widely and successfully used as well as hardening in controlled atmospheres, both methods being employed to minimize deterioration through scaling and decarburization. Experience has shown that it is essential to prevent or eliminate the accumulation of oxide sludge and scale in these salt baths and to have enough sodium cyanide in them at all times to neutralize oxidation. Most controlled atmospheres in tool hardening furnaces are high in carbon monoxide. Unfortunately carbon monoxide is a very poor heat conductor, thus unavoidably extending the length of the heat treating cycle. Furthermore, carbon monoxide is a carburizing agent and carbon pickup may increase the carbon content of fine tool edges, causing them later to chip, rub and fail prematurely.

The war emergency fostered still another heat treating technique involving sub-zero refrigeration. The principal benefit of this treatment is to complete the austenitic transformation. Super-cooling, so-called, is of limited value to properly heat treated high speed steel for the reason that very little austenite remains untransformed. If the tools have not been properly treated, refrigeration constitutes a partial correction. Sub-zero treatment is of more value to high carbon, high chromium steels because of

the sluggish transformation of their austenite into martensite, usually incomplete after ordinary heat treatment (quench and temper).

Application of High Speed Steels—The various types of high speed steels are still the most popular cutting tool materials in automatic and semi-automatic mass production set-ups. The great majority of cutters, saws, and fluted tools are still made of high speed steels, unless the nature of their service requirements permits the employment of carbon toolsteel or some other lower alloy cutting tool material. High speed steels have continued to handle such exceptionally tough jobs as aircraft engine cylinder barrel finning, and to constitute most types of thin grooving tools and cutting-off tools whose fragility and lack of support prevent the use of carbide cutting tools. Even with high speed steel, it is necessary to avoid holding a cut-off blade at an excessive back rake angle, because the resultant cutting angle is insufficient and frequent breakage is likely. This is sketched in Fig. 1. High speed steel has also been widely used for certain types of punches and for heavy roughing cuts on cast and wrought armor (tank turrets and tank hulls).

Standard Tool Life Tests—One of the most difficult and intangible tasks facing the users of cutting tools has always been the correct evaluation of cutting tool performance on the basis of accelerated service tests. The American Society of Mechanical Engineers has sponsored such a tool life test for high speed steel issued by the American Standards Association. It is to be hoped that this test will be widely and carefully used, so that a body of experience can be accumulated for correlation with actual service of the steels so tested.

Sintered Carbides have played the stellar role in the present conflict. With tools tipped with sintered carbide, metal can be removed most rapidly in any race against time, and time is of the essence in wartime. Furthermore, carbide permits the maximum utilization, conservation and productivity of scarce minerals such as tungsten and tantalum, of critical machine tool equipment, of trained personnel and plant facilities.

The war impetus has expanded the facilities of carbide producers to the utmost and extended the use of carbides to new applications. This tendency has further been enhanced by increased knowledge regarding design, manufacture, handling, application and maintenance of carbide tipped tools.

Types of Sintered Carbide—Japanese occupation of Malaya and the Straits Settlements effectually cut off our imports of tantalum ore. Even before the war, however, there was a marked tendency toward reducing the tantalum carbide content of steel cutting materials. Today the substitution of titanium carbide for tantalum carbide is complete, except for a few isolated instances on work of special nature. This change has been made without sacrificing cutting efficiency—actually, an overall gain in performance has resulted.* Straight tungsten carbide (without either titanium or tantalum carbide) cuts steel most effectively on such applications as rifle drilling, turning stainless steel, plunge cut form tools, reamers, saws, end milling, and, in fact, wherever abrasion resistance is more important than resistance to cratering under the chip. Such uses include the harder, more abrasive steels

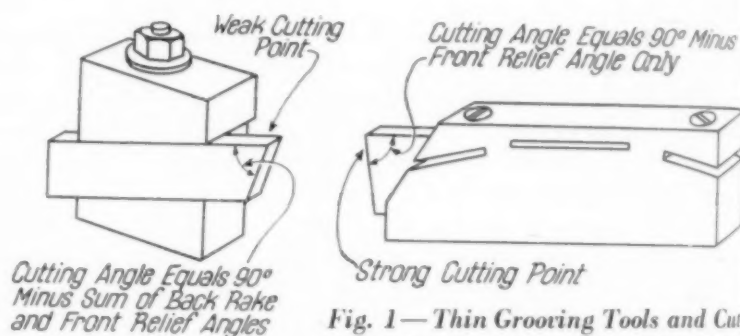


Fig. 1—Thin Grooving Tools and Cutting-Off Tools Made of High Speed Steel Should Avoid Excessive Back Rake

under light feeds, shallow cuts and high speeds.

The nature of the hard sintered carbides is fairly well known. Unlike toolsteel, they are inherently hard and relatively impervious to heat treatment. Their hardness is unaffected by sudden heating or cooling. Mechanically, however, they are sensitive to thermal shock; consequently they should be heated and cooled slowly to prevent stresses which may cause cracks or rupture. (After tipped tools are brazed, with localized heat, they should be cooled slowly, as in mica.)

The outstanding characteristic of sintered carbides is of course their intense hardness and consequent abrasion resistance, both of which qualities they retain to very high temperatures, thus exhibiting remarkable hot hardness. These qualities enable a carbide tipped cutting edge to

*Prof. Gregory Comstock of Stevens Institute of Technology reports, after an investigation for the U. S. Technical and Industrial Intelligence Committee, that the Germans have been making much use of a cutting material made of vanadium and titanium carbides, bonded with metallic nickel, thus freeing the available tungsten for other indispensable uses.

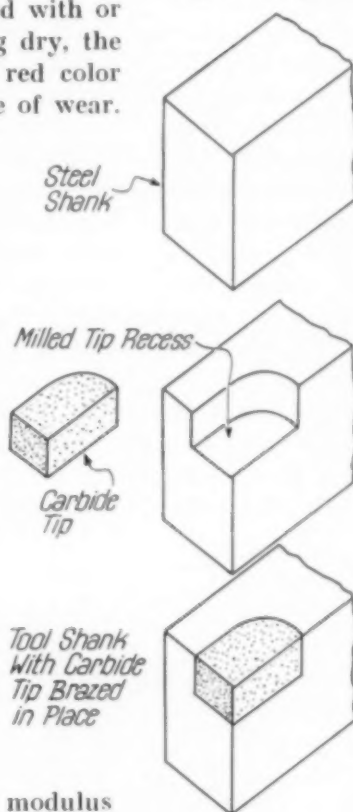
withstand very high cutting speed even on hard metals or abrasives. They may be used with or without a cutting fluid. When cutting dry, the point of the tool may attain a bright red color without perceptible increase in the rate of wear.

Sintered carbides are roughly three times as hard "on the Brinell hardness scale" and have twice the specific gravity of toolsteels. Their strength in shear and bending is limited, but they have the highest compressive strength of any known material. These qualities suggest a composite type of tool, wherein the carbide tip is an insert in a supporting toolsteel shank. The latter should be as large and particularly as deep as conditions will permit. The amount of overhang, or the distance the cutting point protrudes from the support of the tool block, should be a minimum. Otherwise tool shank deflection under the load imposed by the cutting forces may break the tip. The physical property which determines the rigidity of a metal is the modulus of elasticity. The modulus of steel is about 29,000,000 psi. and cannot be altered by heat treatment; of sintered carbide it is in the neighborhood of 80,000,000 psi.

Tipping Tools With Carbide—The usual method of joining the sintered carbide cutting tip to the toolsteel shank involves cutting or forming a recess in the cutting end of the steel shank to accommodate the carbide tip. (See Fig. 2.) Attachment may be by means of brazing or mechanical clamping. Various types of relatively low-melting hard solders are suitable for the brazing job, and commonly used types are listed in the table. The necessary heat for brazing can be supplied by an oxy-acetylene torch, a gas fired or electrically heated furnace with or without controlled atmosphere, or by means of electromagnetic induction (high frequency currents). Frequently electrolytic copper foil is used as the brazing medium. A detailed discussion of brazing methods is unnecessary here because it may be found in the handbooks of the various suppliers and makers of carbide tools.

Tips may be held in place mechanically by wedges or clamps, or the tip may be drilled and

Fig. 2—Steps in the Tipping of a Tool Shank



counterbored to receive a shoulder screw to hold it in place upon the tool shank.

A very considerable improvement in carbide tool performance has resulted from better methods of grinding and lapping to produce keen, smooth cutting edges and chip rubbing surfaces. The diamond impregnated grinding wheel, used for dressing carbide tips, has assumed many new forms in addition to the original resinoid bond, such as the metal bond and, finally, the vitreous bond. Diamond wheels cut carbide freely and quickly produce finely finished tools.

Applications—The first wartime requirement which appeared to be of greatest urgency was naturally the manufacture of projectiles, naval guns and army artillery.

Sintered carbides were literally the only means to produce the astronomical quantity of shell required. Sintered carbide tools permitted the high speed production by which the quantity required could be provided in the time available. Sintered carbide tools finished shell more precisely than ever before. In practically all shell plants, finish turning was *after* heat treatment. Cutting was done on hard, tough steel, yet the accurately finished surfaces greatly improved ballistic performance and accuracy of fire.

Perhaps the greatest improvement in the art of machining metals during the war period was the introduction of "hypermilling". The tools required the tipping of sintered carbide edges (with *negative* rake) on milling cutters. This

Brazing Materials for Sintered Carbides

TRADE NAME OF MATERIAL	MAKER	FLUX RECOMMENDED
For use with oxy-acetylene flame		
Easy-Flo No. 3	Handy & Harman	Handy Paste
Tobin bronze (Oxweld 25-M)	Linde Air Products Co.	Brazo
Castolin No. 16	Eutectic Welding Alloys Co.	Autochemic 16-B
Brazing brass	Any brass manufacturer	Krembs Fluxine
For use when furnace brazing		
Electrolytic copper	Any brass manufacturer	{Firth Braze-rite, Borax or Fluxine

permitted the ultra high speed machining of steel by milling machines. This new technique increased the speed of production and the quantity of parts for guns, armament, munitions and all types of combat vehicles. Hypermilling, in fact, extended our ability to cut hardened materials, including cast and wrought armor. The greater accuracy of hypermilled surfaces often eliminated grinding to finished dimension, thus saving time all along the line.

The principle of high speed milling was extended to include aluminum alloys on such parts as cap spars which are one of the principal structural elements of an aircraft wing. On smaller aircraft, these cap spars could be extruded, but on the larger bombers and cargo planes, they had to be forged, and the forging required machining. Carbide tipped cutters were

as well as gear shaper and generating tools. A current project concerns the hobbing of laminated plastic automotive timing gears, made of material which is so abrasive that high speed steel or nitrided hobs are practically useless.

While it is a use that has nothing to do with machine tools (except that a projectile may be thought of as a high speed punch) it should be added that carbide has been used in the form of shell cores. The 76-mm. high velocity rifle carried by our tank destroyers shoots a projectile whose core is of sintered carbide approximately $1\frac{1}{2}$ in. in diameter and 5 in. long, weighing in the neighborhood of 4 lb. This core is sheathed by an aluminum alloy and steel casing. It was a deadly foe against enemy armor, not only for its remarkable penetrating power but for its fragmentation, once inside the tank hull.

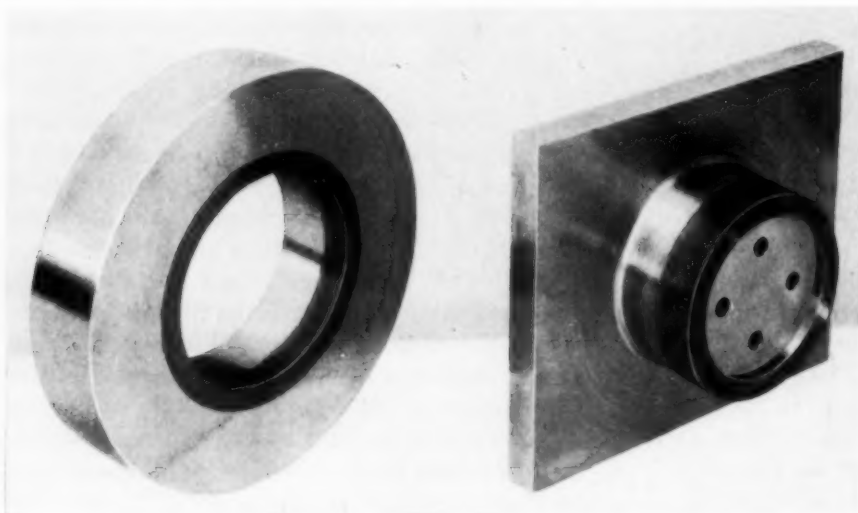


Fig. 3 — Sintered Carbide Inserts, Trade-Named "Diecarb", After Blanking a Half-Billion 0.025-In. Silicon Sheet Laminations, Averaging 50 to 60 Million Pieces per Grind

employed for literally plowing off vast quantities of aluminum alloy in incredibly short times, as can readily be seen from the fact that cutting speeds ranged up to 20,000 ft. per min., with feeds up to 225 in. per min., removing 300 cu.in. of metal per min.

Sintered carbides are being widely and successfully made into virtually all types of punches and dies for blanking, piercing, forming, and other operations on sheet metal. In addition to increased speed of production and much greater life between sharpenings, more accurate work is produced with less tendency to burr the edges or buckle the stock.

Rapid strides are being made in the application of sintered carbide to gear cutting in the form of conventional milling cutters, gear hobs

Lessons Learned — In conclusion, we can briefly list some of the outstanding things which were learned about metal cutting and metal cutting materials during the war period.

First, we found that cutting efficiency of high speed and other toolsteels was sacrificed if tungsten and vanadium were limited in content.

Second, a conservation program was necessitated by the demands of the armed forces in order to make sure that enough carbide tools were available to produce the required implements of war.

Third, we found that the cutting of hard, tough, and heat treated materials was

thoroughly feasible with carbide tipped tools.

Fourth, we found that metal could be removed at the highest rate by carbide tools.

Fifth, a need became apparent for larger, more powerful, and more rigid machine tools in order to realize more fully the ability of carbide tipped tools to remove metal.

Sixth, we found that it was possible to machine parts for closely fitting mechanisms to much narrower tolerances than were hitherto thought possible.

Seventh, we found a remarkable extension of carbide tooling to cutting applications previously untried or unsuccessful.

Carbide tools point the way to a more abundant life. More and better tools mean more and cheaper labor saving appliances.

By W. Spraragen
Director
Welding Research Council
New York City

Five Years of Progress in Welding

"IN APPRAISING the various factors which have played an important role in enabling the merchant shipyards of this country to hang up their marvelous production record, it is believed that welding as the 'tool of construction' would rank well near the top. In fact the entire emergency shipbuilding program has been founded on the essentially all-welded ship." The quotation is from an address made about a year ago by Rear Admiral Howard L. Vickery, vice-chairman of U. S. Maritime Commission. On the same occasion Col. Scott B. Ritchie of the Office of Chief of Ordnance, in contemplating what would have been the picture without welding, stated: "Our tanks would still be riveted and therefore more vulnerable — our artillery would be heavier and either be less maneuverable, or have less fire-power — our vehicles would carry more dead weight — our planes would be slower — and on and on throughout the long range of the weapons of war."

Some 350,000 welding operators are involved in these operations, ranging from highly skilled workmen to operators of automatic welding machines. Probably 15% are women.

This general review of progress and a short look ahead is bound to be sketchy for there are four main process divisions — namely, arc, gas, resistance and thermit welding. (See Fig. 1, overleaf.) Each have literally half a dozen sub-divisions and there are quite a few almost inseparable allied processes, the most important of which is oxygen cutting. These processes are used to a

more or less extent by the entire metal working and fabricating industry.

The Scientific Background — Welding and its allied processes generally involve complex metallurgical phenomena owing to changes which take place rapidly (at times in measured fractions of a second) at extremely high temperatures (arc temperatures are on the order of 10,000° F.) and in concentrated space. Its problems have intrigued and puzzled the leading mathematicians, physicists, physical metallurgists, chemists and plastic flow experts.

The welding industry has been fully cognizant of its opportunities and its need for fundamental knowledge. For a period of at least 30 years it has patiently sought to substitute knowledge for rule-of-thumb methods, to understand the reason why rather than to be satisfied with a cut-and-try solution. Moving slowly at first because of lack of funds and talent, the research work has gone forward at an ever accelerated pace reaching a crescendo in 1944 of an expenditure of several million dollars, about half of which came from the government.

A few important failures of ships and storage tanks have had the necessary salutary effect on the unbridled enthusiast and have brought home to all the need for further and more careful studies and the need for more rigid controls in applying the knowledge and experience now available. Strangely enough almost everyone is involved in this soul-searching — the steelmaker, the designer, the fabricator, the inspector, the testing and enforcement agencies, the workman and the scientist. It is not surprising therefore that a major effort has been made to secure a better knowledge of weldability and stresses, and these matters must be given an important share in any review of the present status of welding.

Failures are due to overpowering stress, and the weld stress problem may be divided into two parts. The first relates to transient conditions prevailing during welding and subsequent cooling to ambient temperature. This we will arbitrarily call the *weldability* problem. The second part

relates to conditions existing after the weld has cooled down to ambient temperature. This we will again arbitrarily call the *stress* problem.

The Weldability Problem

One of the major problems in weldability is to develop a welding procedure and technique which will result in suitable cooling rates for the base metal (steel) next to the weld. This procedure and technique is a function of the composition of the base material (steel), its geometry, initial temperature, surrounding temperature and rate of heat input. Studies of all these factors have been made and reported. There are corresponding factors related to the weld metal. In both, the conditions of restraint are of paramount importance. It is necessary, therefore, to study other factors such as character or composition of the weld deposit, rate of volume deposit, techniques affecting the quality of the weld deposit and, above all, the conditions of local and general restraint. For example, the first layer of a fillet weld deposit from one type of electrode may crack on cooling whereas that of another type may not. However, cracking with the first type may be avoided by making provision for contraction by slightly separating the edges. *General* restraint can cause cracking on cooling in the weld, in the base metal adjacent to the weld, or even in parts of the structure remote from the welded joint.

Nearly every fusion weld must "flow" plastically on heating and cooling. If the condition of restraint is sufficient to cause the shrinkage stress in the particular volume and type of weld metal to exceed the fracture strength before the metal can flow plastically as it cools, the weld metal will crack. As part of the arbitrarily defined weldability problem, the welding engineer has learned how to deal with these conditions of restraint. A few of the common devices are pre-heating of parts, thermal stress relieving the entire structure before it cools, changing the volume or character of the deposited metal such as by the use of austenitic electrodes, peening,

wandering sequence, step back methods of welding, small electrodes, block welding and a host of other devices.

Cracking probably is the most potentially dangerous and certainly the most alarming defect in a weldment. Cracks may occur in the heat-affected zone of the base metal or in the deposited metal proper. Weld metal, cooling under restraint, will crack because plastic flow is inhibited, thus causing the shrinkage stress to exceed

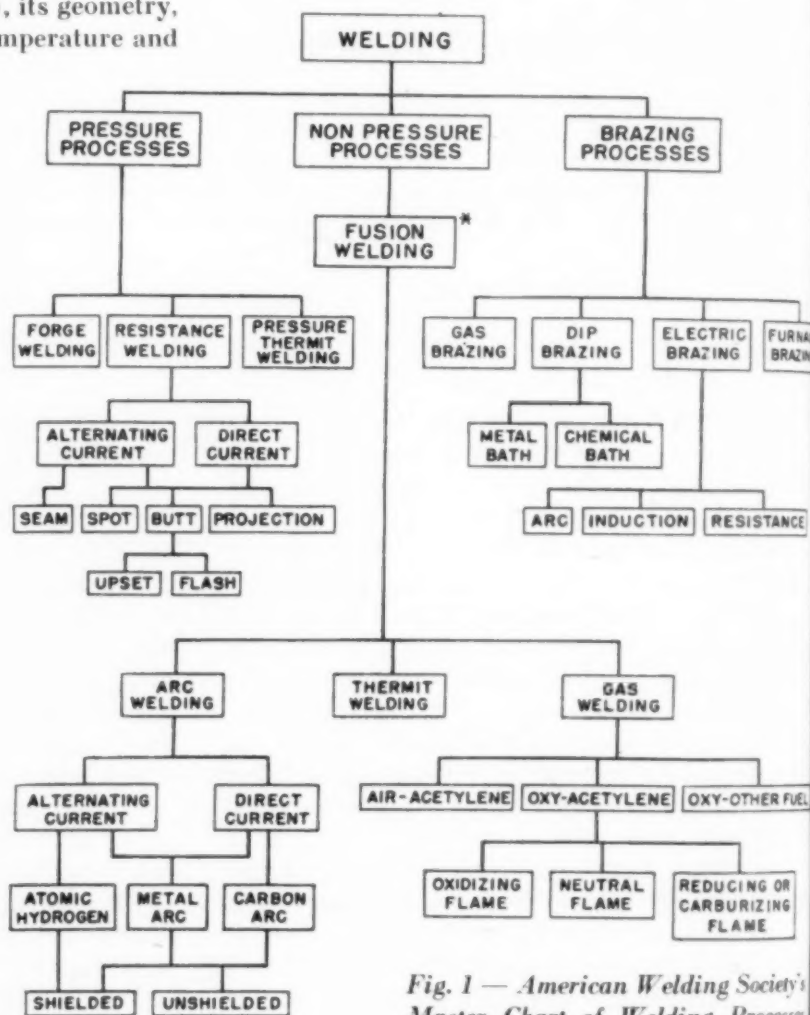


Fig. 1 — American Welding Society's Master Chart of Welding Processes

the fracture strength of the metal. Cracks in the base metal probably occur at comparatively low temperatures. Weld metal cracks may occur at either high or low temperatures. The ability of the base metal to flow plastically is decreased by restraint and also by hardening due to the heat effect of the welding. In order to avoid base metal cracking, steel for welding should be so selected that the loss of ductility due to the heat

*The term "fusion welding" has been established by long usage. It is recognized, however, that some of the other welding processes involve fusion.

effect still leaves adequate toughness (strength and ductility) to permit enough plastic deformation to avoid cracking during the welding cycle. Means for so doing have been set forth in the American Welding Society's *Guide Book to Weldability*.^{*} A more direct test of ductility in the heat-affected zone, known as the notch bead test and described by the Naval Research Laboratories, also serves the purpose, provided heating and cooling conditions have been adequately matched to the intended application. The metallurgical theory is well set forth in the recent work on weldability at Rensselaer Polytechnic Institute and Lehigh University. (These investigations neglect the effect of hydrogen from electrode coating when welding hardenable steels, which effect will aggravate any loss of ductility.)

Instances may arise wherein the original toughness (strength and ductility) of the base metal, without any reduction due to heat effect, is inadequate to the purposes of welding. Usually such steels are rejected on other grounds but not necessarily. If plain carbon steels are involved, a bend test in addition to the tensile test is generally sufficient for assurance on this score. No generalizations can be made which invariably apply in specific cases with respect to types of steel which may or may not be suitable. Broadly, however, plain low carbon steels, and low carbon, low alloy steels will be suitable for welding.

Magnetic powder testing and X-ray testing are generally accepted means for detecting cracks. Each of these has its limitations. Sonic and supersonic methods, such as described in *Metal Progress* last month, have been used on a limited scale and will bear further investigation. There is a lack of non-destructive methods for complete detection of weld cracks.

The Weld Stress Problem

Let it be assumed temporarily that a welded structure is crack-free on cooling. Experience has indicated that this structure presents a variety of problems singly or in combination. It is difficult to assign to them an order of importance. Each will be mentioned briefly.

Stress Raisers—Faulty design or imperfect workmanship is generally the cause of the most serious geometric stress raisers. Sharp corners can usually be made rounded. Excessive reinforcement of openings without a gradual tapering of cross section is another prevalent cause

^{*}See also a general discussion on "Weldability of Steel" by Martin Seyt in *Metal Progress* for February 1944 and several comments incited by that article, grouped together and published in July 1944.

of trouble. Stress raisers due to defective workmanship are not always detected. Undetected shrinkage cracks have already been referred to in the section above on weldability. Cracks due to incomplete fusion, undercutting, and improper shearing are unfortunately sometimes ignored, yet the stress intensity at the end of a small, sharp crack may be many, many times the general stress intensity in neighboring parts.

Small wonder then that every expert considers these stress concentrators as the focal points of practically all of the trouble. After cracks start to lengthen, the resultant reduced cross section and increased concentration at the ends of the crack usually make matters progressively worse. Moreover, cracks may be propagated by reaction stresses. As will be seen later, the high notch sensitivity of some steels at cold temperatures when plastic flow is restrained greatly increases the chances of failure.

So much has been written about the necessity of avoiding notches in design that it is redundant to dwell at any great length on this feature. However, it should be pointed out that the combination of sharp notches, low temperatures and high notch sensitivity is an invitation to disaster.

Quality of Steel—The welding engineer knows how to handle a particular situation depending on the ordinarily reported chemistry of his steel. Yet there are vast differences in steels, lot to lot, even when obtained under the same specification, such as A.S.T.M. A7.

For example, for low temperature work a number of experts have agreed that notch sensitivity is dependent on steelmaking practice—specifically, deoxidation. The steelmaker knows how to produce steel for this class of service but recently has demanded a substantial cost extra.

In most low alloy steels a quenching and tempering treatment changes the character of a low alloy steel under low temperature impact from a brittle steel to one of extreme toughness.

Different ferritic steels and microstructures may test alike, as far as notch-bar values and tough fractures at room temperature, but as the testing temperature is progressively decreased some steels show abrupt drops in the curve relating temperature and ft.-lb. of energy absorbed and the appearance of brittle instead of tough fractures. This drop usually occurs in separate specimens of the same steel over a range of temperature and some of the fractures within this range are brittle and some are tough. It is known as the transition range.

Notch sensitivity of the plate steel does not evaluate the notch sensitivity of the structure in

the heat-affected zone. In most welding steels, the transition range of temperature of the heat-affected zone is higher than that for the plate material. The effect of melting practice as it is related to grain size in the heat-affected zone may be controlled by deoxidation practice, although a satisfactory lack of notch sensitivity in the plate material does not necessarily indicate equally satisfactory notch toughness in the heat-affected zone. This same comment can be made with regard to the quenched and tempered steels. In general, welding does not improve notch sensitivity, and the notch sensitivity of the heat-affected zone thus becomes the lower limit for the welded specimen.

Low Temperature — At low temperatures the ability of metal to flow in a plastic manner changes decidedly, generally for the worse. Yield point and ultimate strength generally rise, and usually the fatigue properties — as measured by an increase in endurance limit — are also improved. The impact properties, however, for some steels fall off abruptly as the temperature drops below 32° F. — sometimes at even higher temperatures. For example, one side of a ship or storage tank in the sun while the other side or another part is in the water or in the shade at low temperature very often potentially is in trouble from residual stresses caused by rigidity of structure, and the variation in properties of the same steel at different temperatures. All that is required is an impact blow to set off the charge. It is possible that the stresses due to loading or other factors, such as decrease in temperature, may increase to such an extent as to cause a cleavage type of fracture without the necessity for any impact. There is need to know the intensity of residual stresses in a plate caused by wide differences in temperature over short distances and the magnitude of the deformation necessary to cause fracture.

When some ferritic materials are required to deform at low temperatures under conditions of restraint against deformation, as in the presence of a notch, or when a load is applied to them with extreme rapidity, they show extreme brittleness. Without the notch or the impact load they are tough, even at low winter temperatures.

There is definite evidence that final failure of some of the bridges in Europe came about through the extension, in cold weather, of existing cracks resulting from welding operations. It has been established that for a given steel the change from tough to brittle behavior is a function of sharpness of notch, rate of applied loading, and temperature, and the importance of each

factor may be quantitatively evaluated for critical conditions.

Strain Aging — Metallurgical studies indicate that certain steels are susceptible to a phenomenon known as strain aging. If such steels are strained plastically and then merely allowed to rest for a few weeks at ordinary temperatures (70 to 80° F.) they lose part of their ductility and develop a very high notch sensitivity. Furthermore, steels that are susceptible to strain aging generally have their notch sensitivity greatly increased by moderately low temperatures (32° F.). It has also been determined that strain aging can be accelerated by heating the steel, 2 hr. at 212° F. being equivalent to several weeks at 70° F.

Rigidity of Structure — Welding gives a continuous structure with joints that cannot slip moderately, in the same manner as a riveted structure. Moreover, the crack-stopping abilities of a riveted joint, by virtue of its non-continuity, are not available in the usual welded joint.

The failure of materials under compound stress conditions is, of course, a very complicated subject. However, all the evidence available indicates that there are two main types of failure, shear and cohesive (the latter defined as a true tensile failure due to overcoming cohesive bonds); that the imminence of shear failure depends principally upon the relation between the maximum shear stress present and a fundamental physical property of the material which might be called its inherent shear strength; and that the imminence of cohesive failure depends principally on the relation between the maximum tension stress present and a fundamental physical property of the material which might be called its cohesive strength.

Other characteristics of the stress condition besides the maximum shear stress and the maximum tensile stress undoubtedly have some effect. For instance, the third principal stress may have a maximum effect of 15% or so on shear failure, and there is evidence that the normal stress on the surface on which shear failure is occurring has an influence as to whether the failure will be plastic or brittle. The above remarks apply particularly to failure under static load, but it is probable that maximum shear and tensile stresses are also of major importance in connection with fatigue, shock and creep failures.

In pure tension, there is a fixed ratio of 2:1 between the maximum tensile stress present and the maximum shear stress present. A conventionally "ductile" material is simply one having (at room temperature) a larger ratio than 1:1 between its cohesive and shear strengths, so that

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it fails by shear when tensile and shearing stresses are equal; on the other hand a conventionally "brittle" material is simply one having at room temperature a smaller ratio than 1:1 between its cohesive and shear strengths, so that it fails cohesively when tensile and shearing stresses are equal.

"Ductile" and "brittle" behavior should not be considered as inherent properties of any given material. Examples could be cited of conditions under which cast iron or rocks may be made to behave in a "ductile" manner and, conversely, the most ductile steel may be made to behave in a "brittle" manner by stressing in a certain way.

Residual Stresses—A great deal of time and money has been spent measuring residual stresses. Where residual stresses have been averaged over an appreciable distance they are often of yield point magnitude. However, the technique of stress measurement has not been perfected to a degree where we can, with reasonable certainty, ascertain the maximum stress intensity when the stress gradient is steep. Moreover, we know that by continuous plastic deformation we can make the yield point stresses approach the ultimate strength, even in uniaxial tension.

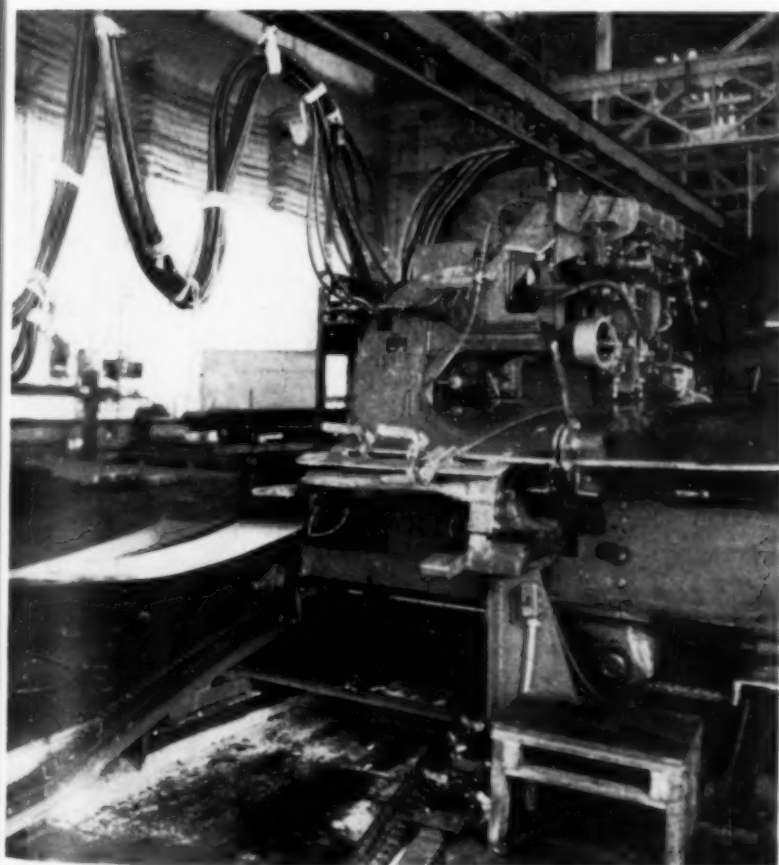


Fig. 2—Automatic Spot Welding Machine for Making Joints in Passenger Car Roofs. (Pullman-Standard Car Mfg. Co.)

Measurements of residuals under various stages of triaxiality have not as yet been made. Weldability investigations have shown that if the constraint is too great to permit plastic flow in the particular volume of welded metal and adjacent base metal, cracking will result on cooling.

Many investigations have been made as to what happens to residual stresses when the structure is put into service. Experimentally it has not yet been shown in the laboratory that these residuals cause a structure to behave a great deal differently from one without them. This statement needs slight modification, as will be shown. Laboratory tests have demonstrated that if plastic flow has time to take place, it will take place, and there is little to fear from these residuals under either fatigue or static loading in so far as the useful life of the structure is concerned. A few meager experiments indicate that there is some slight difference when impact is involved at low temperature between a structure that contains residuals and one that does not. All of these investigations relate to stress conditions which can be classified as of a biaxial nature.

Practical experience indicates that this general statement cannot be carried over to thick materials where considerable triaxiality is involved in the stress distribution. An example very often cited is that of a 2-in. thick section of the Boulder Dam penstock which cracked when dropped on its way to the annealing furnace, and is contrasted with a similar stress-relieved section dropped in the same way which did not crack. But thermal stress relief may have brought about this improvement not altogether because of reduction of residuals but rather by eliminating hydrogen and reducing peak hardness.

Thermal stress relieving is also useful to bring about dimensional stability, particularly in structures that require careful alignment after machining.

Laboratory tests and service results have indicated that there is a gradual decrease in residual stresses when the structure ages, especially when different parts of it are at different temperatures, or where service loads plus residuals exceed the yield point.

A stress relieving treatment of parts of restrained structures

by localized heating may iron out local peaks in the residual stresses but introduce large reaction stresses. In some applications stress relieving at low temperature is quite effective in reducing peak residuals.

It is also suspected that high residuals in steels which are susceptible to strain aging expedite a phenomenon known as "stress corrosion".

Lastly, there is need for further study of the residual stress distribution across the thickness of welds.

Graphitization of Steam Lines

Segregated graphite has been found (January, 1943) alongside a welded joint in a steam pipe of carbon-molybdenum steel at the Springdale Station of the West Penn Power Co. This was as surprising as it was disturbing. The graphite appeared as dark streaks or "eyebrows" about $\frac{1}{8}$ to $\frac{3}{16}$ in. away from the weld. Closer inspection showed that they followed the outer contours of the heat bands produced by welding and that they were extremely narrow. When fully developed, these graphite bands ran across the entire cross section of the pipe and, of course, made the pipe very brittle at that place. Exam-

ination has shown that the graphite segregates or concentrates at the place where the stock was heated during welding to approximately the A_{c1} point of the steel. In multipass welding, these isothermal lines of successive passes intersect each other so that, more precisely, the graphite streak follows the outer envelope of the A_{c1} isothermal lines.

Research was started at Battelle Memorial Institute for studying the fundamental causes of graphitization. Further objectives were to determine what steps could be taken to "cure" graphitized joints which may exist in present lines, and to prevent further graphitization, and to determine which steels would best resist graphitization. The steel in both wrought and cast sections of pipe lines which have seriously graphitized is known to have been deoxidized with about 2 lb. of aluminum per ton.

The addition of aluminum to steel (during deoxidation) also affects some of the finer details of the structure of the carbide constituent, particularly by tending to spheroidize the carbide and to produce what has been called an "abnormal" structure. It is held by some that the spheroidal form of carbide is more easily graphitized. There is not much doubt that the molybdenum in these steels is a retarder of graphitization — or at least a mild stabilizer.

The treatment of a line which already shows graphite will depend upon the condition found. If graphitization has proceeded only to an intermediate state, it should be possible to redissolve the graphite and restore the joint by heating to about 1700° F. for 2 hr. This would amount to a normalizing treatment.

In cases of severely segregated graphite, it has been necessary to cut out the old joint and reweld. A favorable postwelding treatment might be either normalizing, as was just mentioned, or stress relieving at 1300° F. or higher. Both treatments will at least postpone further graphitization; normalizing might eliminate it, for all practical purposes.

Carrying out the idea that aluminum deoxidation definitely promotes graphitization, it has been proposed to limit

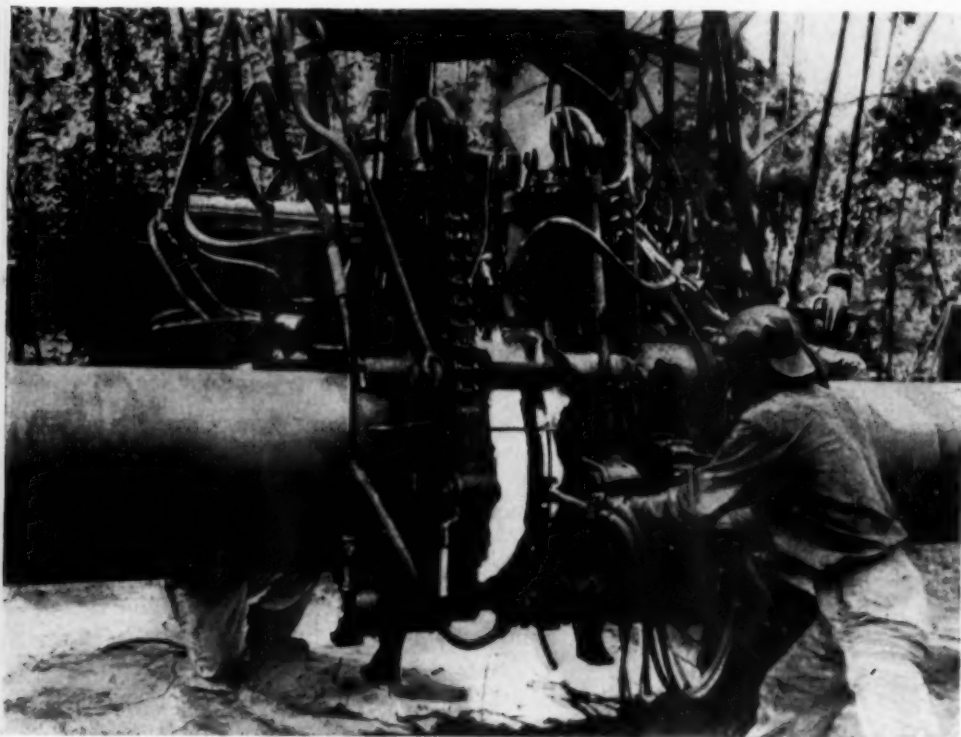


Fig. 3—Clamp and Blowpipe Equipment for Pressure Welding (Solid Phase Welding) of Pipe in 24-In. Overland Line. One set of clamps acts as a holding vise; end pressure is applied by the other set of clamps, and is powered by the accompanying tractor-crane. The annular arrangement of heating blowpipes may be reciprocated manually during the heating. Courtesy Linde Air Products Co.

the aluminum addition to $\frac{1}{2}$ lb. per ton. A close equivalent of this is the requirement that the steel must have a McQuaid-Ehn grain size of 1 to 5, with complete "normality". Another recommendation that is being seriously considered is the addition of chromium to stabilize the carbide; the minimum amount has not yet been established, but steels with 0.25 to 1.50% chromium are being investigated.

Weldability of Specific Steels

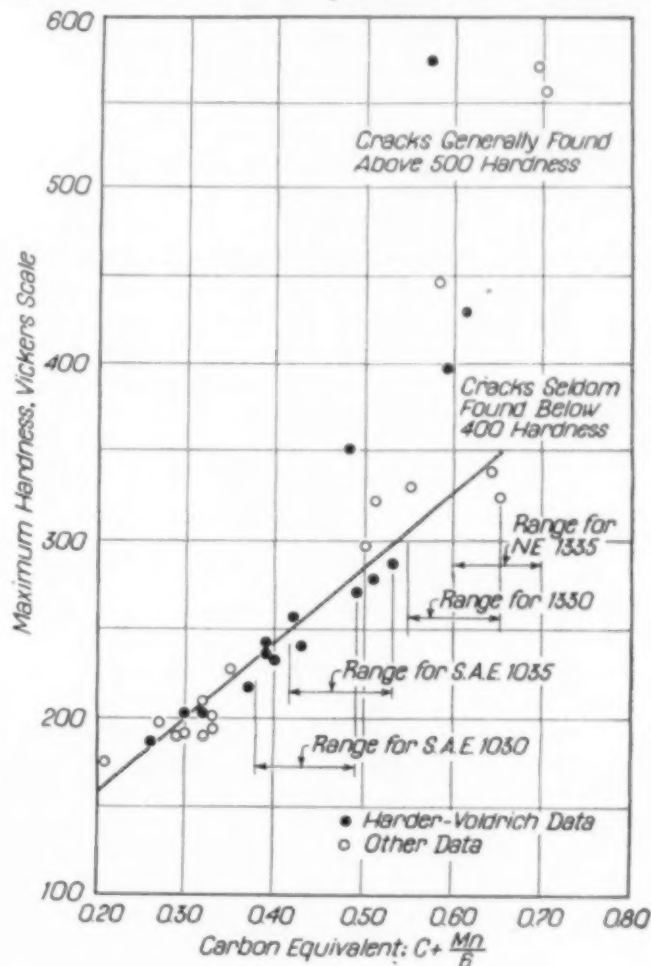
A great deal of experimental work on specific steels has been carried out here and in England. It would take a good sized book to give the results of all of these investigations. The comparative hardening power and cracking tendencies for many of the useful alloying elements, singly and in combination, have been explored and the results recorded. Methods of testing new low alloy steels are established in the "Guide Book to Weldability".

The question of weldability of carbon-manganese steels is, however, particularly pertinent to industry, in that these steels represent a large portion of the tonnage to be welded in civil and mechanical engineering structures. The essence of the problem is the avoidance of cracks during the welding of those structures which are to be stress relieved subsequent to welding, and the maintenance of adequate ductility next to the weld in those structures which are to serve in the as-welded condition. These remarks in general also apply to low alloy steels.

In one series of investigations where plain carbon steels only were involved, the criterion of hardness was decided upon. It is generally agreed among welding engineers that, to prevent cracks in the carbon-manganese type of steels, the Vickers-Brinell hardness should not exceed 350 Brinell. This figure may be exceeded where the conditions are such that nothing but compressive forces result from the welding — a condition that might not be easy to insure. Brinell 350 may not be low enough in some structures where extreme restraint is involved. This figure seems to be satisfactory to use when the structure is to be stress relieved after welding.

If the structure is to be used as-welded, the type of service determines the amount of ductility required next to the weld. A value of 250 Brinell for these steels is conservative and 200 is generally considered satisfactory for almost all applications. Steels with less than 0.25% carbon and less than 0.50% manganese present no problem from the standpoint of loss of ductility next to the weld. Steels with more than 0.25% carbon and slightly over 0.50% manganese are border-

Fig. 4 — Relation Between Maximum Weld-Bead Hardness and "Carbon Equivalent" in Carbon-Manganese Steels ($\frac{1}{2}$ -In. Plate at Room Temperature). Increasing plate thickness, decreasing its temperature, and decreasing diameter of electrode or length of weld move the curve upward — and vice versa*



line as to weldability when they are to be used in the as-welded condition, but present no problem when they are to be given a thermal stress relief. This is true regardless of the thickness except that such steels may be considered weldable, even for service in the as-welded state, in light plates up to $\frac{1}{4}$ in. The steels having more than 1% manganese and more than 0.30% carbon may not be considered weldable (from the point of view of hardness produced) without precautions, such as preheating, even in lighter plate. This series of investigations* showed that the total of carbon plus manganese divided by six ($C + \frac{Mn}{6}$) may be used as an index in the ranges of 0.20 to 0.30% carbon and 0.50 to 1% manganese. (See Fig. 4.)

*See "Weldability of NE1330 and NE1335 — Laboratory Tests", by Oscar E. Harder and C. B. Voldrich, *Metal Progress*, March 1943, page 409.

For many of the stronger low alloy steels, the quenching of that portion of the steel adjacent to the weld which has been heated into the austenitic range may be sufficiently rapid to prevent complete transformation to the tougher and softer pearlitic products, with the result that more or less of the brittle and hard martensitic constituents will be produced. For the higher alloy steels it may be practically impossible to prevent, by any simple welding technique, the formation of so great a portion of martensite as to render the weld dangerously brittle.

Usually it is desirable to use the largest practicable electrode size in order to reduce this cooling rate. A decrease of speed of arc travel will still further reduce the cooling rate, if the characteristics of the metal being welded make this necessary. If further effort in these two directions involves an objectionable sacrifice of weld metal quality, preheating of the plate may be required. Preheating is also of benefit in improving the quality of the weld metal.

Preheating is particularly effective in improving the quality in the heat-affected zone of those metals which transform only upon cooling below about 1000° F., as, for example, carbon-molybdenum steel (0.18% C, 0.69% Mn, 0.20% Si, 0.46% Mo).

Postheating — In the course of experiments on the effect of heat treatment on the physical

properties of oxy-acetylene weld metal it was found that its ductility could be materially improved by treatment at lower temperatures than are ordinarily employed for annealing welds. This discovery led to more experimentation. It was found that oxy-acetylene welds, when heated from 24 to 72 hr. at temperature of 230° F. or for 1 hr. at 575° F., are improved on the order of 30 to 50% in the value for percentage elongation in tension tests, with corresponding improvement in values for reduction of area. The improvement is obtained both in single-pass and multi-pass welds. Similar marked improvements were found in low alloy steels. The improvement in ductility by low temperature treatments appears to be even greater than that secured by the commonly used stress relief at 1200° F. The values for yield point, tensile strength, hardness, and impact were affected very little if at all by these treatments at moderate temperatures.

Other investigators have found this phenomenon to hold true to some degree for arc welds. Perhaps an explanation is the driving out of hydrogen and other gases.

Only quite recently have the effects of hydrogen on weld metal been studied with any great care. Some evidence has been furnished that hydrogen accounts in some measure for localized internal cracks known as "fish-eyes", and for some loss in ductility and cracking, particularly in arc welds.

An outstanding application of well known metallurgical principles has been in the development of theories and techniques for the spot welding of hardenable plain carbon and alloy steels. Much of this work was done at Rensselaer Polytechnic Institute. In the usual as-welded condition the shear strength of plain carbon steels decreases with increasing carbon content. However, when these spots are tempered in the welding machine the shear strengths increase with carbon content, paralleling the increase of strength produced in the steel by the increased carbon content. Results are shown in Fig. 5. The shear strength of S.A.E. 1045 steel is tripled by such tempering or postheating, and the strength at right angles to the sheet in tension is increased approximately ten times. Tempering thus frees the spot welding process from the limitations imposed by the metallurgical response of hardenable steels.

When ordinary spot welding technique is applied to high carbon steels the drastic quenching action of the cold electrodes produces a brittle martensitic structure in the weld with resultant poor mechanical properties. The new technique

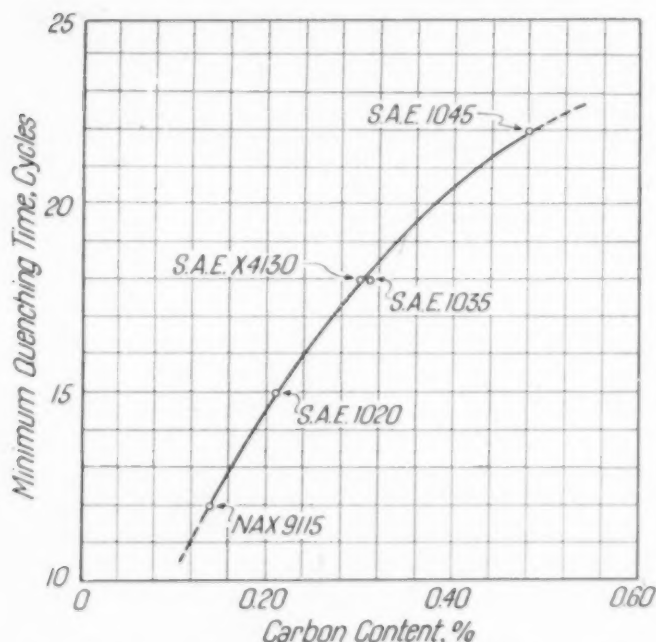


Fig. 5 — Curve Showing That the Minimum Quenching Time Between Spot Weld and Postheating Is Directly Related to the Carbon Content. Conditions are for spot welds made in 6 cycles of welding current, and a 6-cycle postheating current. 0.040 in. steel; flat electrode tips $\frac{1}{4}$ in. diameter. (Rensselaer Polytechnic Institute)

consists of making a weld in the conventional manner, followed by a brief timed interval to allow the weld to quench to the temperature where martensite forms. This is immediately followed by a postheat current of short duration which reheats the weld to just below the austenitizing temperature, and tempers the brittle martensitic structure. In Fig. 5, for example, in 0.040-in. material made with a 6-cycle weld and a 6-cycle heat treat, the minimum quenching time would be 22 cycles for S.A.E. 1045, 18 cycles for 1035, 15 cycles for 1020, and 12 cycles for NAX9115.

Generally, in order to reduce the time required for cooling, the weld should be made in the shortest possible time. The heat treating current must be carefully adjusted to raise the temperature as high as possible without reaching the critical transformation temperature. The time-off between weld and heat treatment has a critical minimum but no critical maximum.

Some Arc Welding Advances

Heliarc—Arc welding in an atmosphere of helium joins magnesium sheets, extrusions and tubing into structures simpler, lighter and stiffer than possible in conventional duralumin construction. At the same time, methods of treating magnesium to make it less combustible and more resistant to heat have been perfected.

Magnesium castings containing foundry defects have been repaired with this process and welds equal to or stronger than the surrounding metal have been obtained. Welding rod of the same alloy as the parent metal is used for castings and wrought alloys. The weld bead appears to be slightly cathodic to the adjoining metal, which causes minor pitting of the original metal adjacent to the weld under severely corrosive conditions.

In this "Heliarc" welding process (Fig. 6), a shield of helium gas envelops the molten metal. Because helium is an inert gas, it prevents oxidation and eliminates the use of a flux. The arc is produced directly between a tungsten electrode and the base metal rather than between two tungsten electrodes (as is the practice in atomic hydrogen welding). Best results are obtained by feeding the filler rod into the tungsten elec-

trode rather than directly in the arc or molten pool. The arc length is generally not over $\frac{1}{16}$ in. A 200-cu.ft. helium tank will supply about 35 hr. of continuous welding with a medium size torch. Automatic equipment has also been developed.

Some progress has been made in the development of welding aluminum alloys in atmospheres of argon, without the use of flux, using either alternating or direct current arcs.

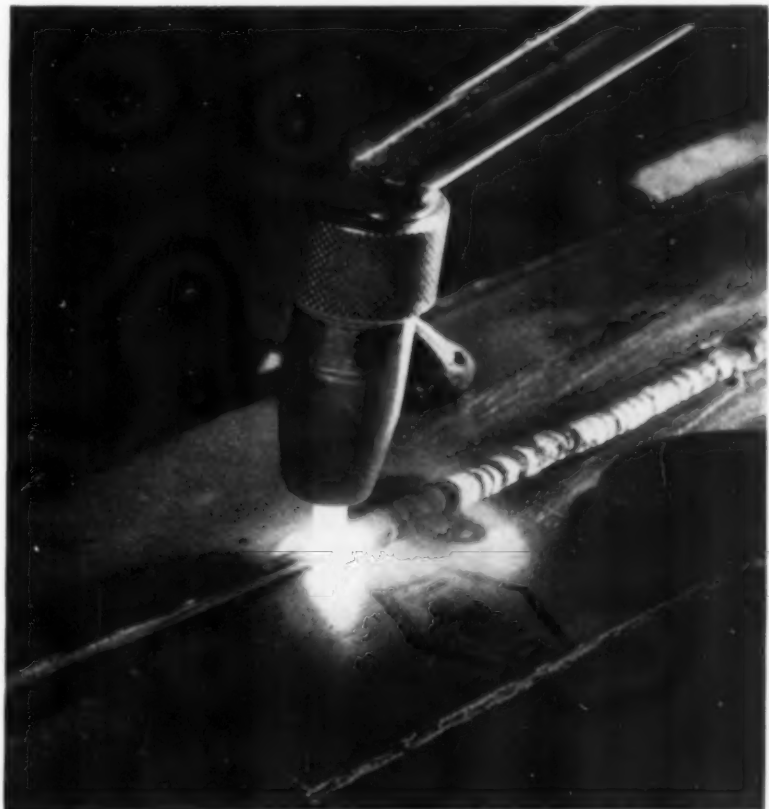


Fig. 6 — Welding Magnesium by the "Heliarc" Welding Process. A platinum electrode contained within the welding head directs a stream of white hot, inert helium gas onto the joint; the welding rod is fed in from the left, producing a very uniform bead. Courtesy Linde Air Products Co.

Multi-Arc—Within the last year and a half a new process has been developed for the arc welding of aluminum alloys called "multi-arc welding". The essential elements are a twin carbon torch, a heavily coated metallic electrode, a metallic electrode holder, the part to be welded and two sources of current. One source is alternating current, which is used to supply the twin carbon torch because it results in even burn-off of the carbons. The other source may be either alternating or direct current for supplying the metallic electrode. Rod size, for a given thickness of stock welded, is not critical; for example, an 0.081-in. butt joint in 52S alloy may be welded

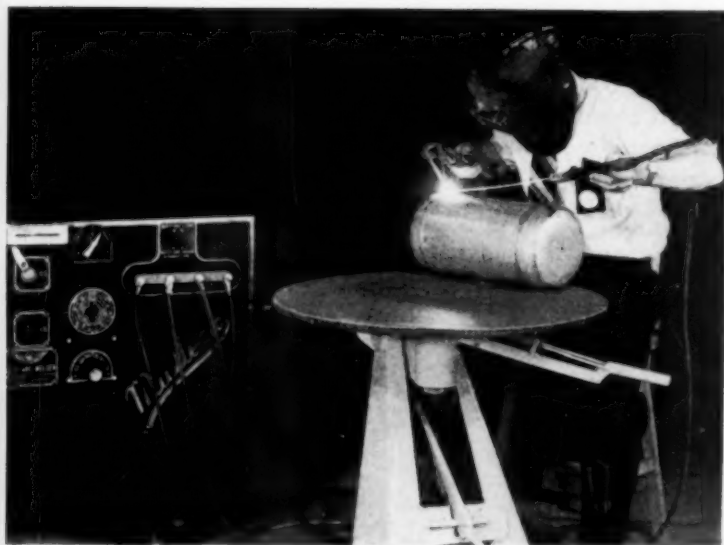


Fig. 7 — Welding a Seam in a Small Aluminum Tank With "Multi-Arc". Double carbon electrodes in the operator's right hand are powered by alternating current; weld rod in his left also serves as an electrode carrying direct current. Courtesy Curtiss-Wright Corp., Airplane Division

with either a $\frac{3}{32}$, $\frac{1}{8}$, or $\frac{5}{32}$ -in. rod, the only difference being in the speed of welding. The best results have been obtained with a heavy flux-coated aluminum rod containing 5% silicon, known as "Aluminweld".

Briefly, the technique is as follows: An arc is started between carbons by depressing a lever. This arc is then moved to within $\frac{1}{8}$ in. of the workpiece where welding is to begin. A circular motion of the arc is momentarily employed for about 5 sec., which tends to preheat the work at the starting point. At this time, auxiliary arcing takes place between one of the carbons and the workpiece. The next operation is the introduction of the metallic electrode, which is held in the left hand, and placed directly over the seam to be welded, contacting the surface of the workpiece at the starting point. (Fig. 7.)

The twin carbons and the metallic rod are now approximately $\frac{3}{16}$ in. apart. Arcing now takes place between the metallic electrode and the carbons, from one carbon to the other, from the metallic electrode to the workpiece and from one carbon to the workpiece. All of this, when confined, produces five individual arcs functioning as one. This arc action causes immediate fusion of the metallic rod deposit and the parent metal and produces a completed weld, free from porosity, with uniform penetration.

Ship and Armor Welding—The use of larger electrodes and faster speeds of welding received particular attention in the shipyards. This technique fitted in very nicely with the theory of

larger heat inputs. There were also developed special electrodes for so-called deep fillet or deep penetration electrodes which tended to place the fillet where it would be most effective.

In the welding of armor plate special ferritic electrodes were developed. It was necessary to give attention to the minutest detail of edge preparation and technique of welding in order to get welds free from cracks and which could resist the stringent ballistic tests.

Another significant development has been the special electrodes for underwater cutting and welding. Special requirements involved protection of the weld-rod coating and means for increasing visibility. Current has been increased by 25% as compared with welding in air.

The Arc—The experimental evidence shows that the force of the arc blast itself by no means completely explains the lack of crater formation when welding experimentally in oxygen-free atmospheres. At the same energy inputs the force of the arc blast in air is always higher than it is in the oxygen-free atmospheres, but at high energy inputs no crater is evident in the inert gases, even when the force is greater than that necessary to form a crater in air. Therefore, some other factor or factors must explain crater formation.

It is impossible to forecast the improvements that will take place in arc welding when there is a more thorough quantitative understanding of the phenomena which take place in the arc. In the meantime the instruments of measurement improve steadily. New tools—as for example, high-speed color motion pictures—will bring us nearer to this understanding.

Resistance Welding

The most thorough investigations have been made to determine the optimum conditions for spot welding the various aluminum alloys and plain carbon steels. A great deal more remains to be done. Nevertheless, useful design values are now available for the engineer for spot welds in these materials, providing the specified procedure is employed.

The characteristic oxide film which is present on aluminum surfaces has always been a serious detriment to the spot welding of aluminum alloys. Its electrical resistance is high and irregularities in its conductivity affect the magnitude of the current and its distribution over the contact areas. Consequently, both the amount and distribution of heat are irregular. These irregularities are reflected in the variable quality of individual welds.

Up to about four years ago many different chemical and mechanical methods have been used for removing this oxide film prior to welding. None of them were considered entirely satisfactory. Moreover, the oxide film re-formed at such speed that the effectiveness of these treatments was in most cases limited to a matter of seconds.

Investigations first correlated surface conditions with a simple measurement of sheet-to-sheet resistance. It was soon discovered that the ideal chemical treatment should be capable of producing a low sheet-to-sheet resistance consistently from day to day. Also the time of treatment should be reasonably short and the operating range sufficiently wide. Several good chemical cleaning formulae and treatments have since been perfected.

Under good welding conditions electrode pick-up of aluminum can definitely be retarded by refrigerating the electrode tips.

Stored energy resistance welding machines, which proved so advantageous for spot welding aluminum and magnesium alloys in the aircraft industry, have also proved their worth on light gages of mild steel. The quick "shot" localizes the heat; with proper electrode care, strength will be uniform and metal finishing costs reduced. Although not as fast as the alternating current equipment, the higher consistent quality of the work makes this process competitive. Flashing and spitting are rare.

Flash welding of $\frac{1}{4}$ -in. and $\frac{3}{8}$ -in. nickel, monel, and inconel rod has been established. In nickel and high nickel alloys it is necessary to maintain the current flow during the initial stages of upset to facilitate proper forging.

Pulsation welding has been successfully applied on the welding of zinc alloy die castings. Spot welds, projection welds, seam welds, and butt welds have all been made. A better understanding of the electro-magnetic stirring action in spot welding has furnished the solution of problems in the resistance welding of dissimilar metals—for example, Cor-ten to 18-8 stainless.

Pulsation welding may be defined as a resistance welding method wherein the flow of welding current (heat) is applied repeatedly while making a single weld, or simultaneous welds, in parts clamped under pressure between electrodes at rest. Pulsation welding is effective when a single long impulse of the same current and heat input is not sufficient to produce the desired weld. It has been used to advantage not only in spot welding but also in line welding, butt welding and projection welding.

Heretofore, spot welding two pieces of 1-in.

plate was considered impractical because of high electrode replacements. With pulsation spot welding, two pieces of 1-in. plate have been welded with no more maintenance than on material one-eighth of this thickness. A typical welding procedure might consist of 10 cycles on and 5 cycles off, repeated 10 times. An annealing cycle can also be arranged by this method, which is sometimes an advantage for alloy steels.

An interesting new development of the past year has been the portable condenser discharge welds for the repair of stainless steel planes. The power plant for a comparable alternating current resistance welding machine must provide at least 50 kva., whereas the discharge welder is used with a 5-kva. power plant. Some of the major developments in resistance welding owe their success partially to the development of low resistance cables.

Solid Phase Welding

During the past five years the theory and application of solid phase welding by the gas process received considerable attention. This is defined as the process by which particles or members are bonded by atomic forces without the presence of a liquid phase at any stage of the process. In practice, smooth surfaces are pressed together so as to exclude nearly all the air, and suitable pressure maintained while heating to effect such bonding. The best known applications are to rail and pipe joints. As shown in Fig. 3 (page 910) the equipment for a large pipe becomes rather cumbersome.

Gas Cutting

Not always are advances dependent on the acquisition of new fundamental knowledge but rather on the inventive genius of one or a group of individuals. Nevertheless these advances are significant and important.

One of the most important production uses of mechanized oxy-acetylene cutting today is the shaping and edge preparation of steel plates needing a variety of multi-faced edge contours. Tolerances practically equal those that are accepted in ordinary machine tool practice. These advances have been brought about through the use of a series of cutting nozzles incorporated in a suitably arranged cluster and so located that any required edge contour can be cut with a single passage of the cutting equipment. An illustration of this preparation method for producing a double bevel with land is shown in Fig. 8. The first nozzle produces the under-beveled surface, the second

nozzle the land, and the third nozzle produces the top bevel. Special arrangements are made to follow variation in flatness of plate without disturbing the fixed side motion.

An investigation has determined whether economy would result from cutting tips fashioned with a divergent exit. Using such tips, one can reduce oxygen consumption by 25 to 40%, as compared with experience with standard tips operating at speeds previously used. One can also operate at speeds 25% greater when using the same oxygen discharge rate as employed with standard tips. These gains result from a narrow stream of high velocity oxygen emerging from the cut and in consequence a narrow kerf, 30 to 50% less than with standard tips.

About two years ago an interesting piece of electronic control equipment was designed to guide automatically the machine completely around a pencil drawing on white paper, independent of an operator once the cut has been started. It is believed that both the quality and quantity of parts, gas cut by machine, are improved because of the accuracy, speed of response, and ease of operation of this control. These features, together with the simple template requirements, assist in reducing the cost of gas cutting.

The cutting of heavy sections of steel (12 in. or more) though not a new accomplishment has been subjected to many uncertainties which have hampered its fullest application. Careful studies have shown that with a suitable balance of operating conditions, the cutting of heavy sections is not fundamentally different from the cutting of moderate sections. Each factor, however, must be controlled much more carefully.

A Look Ahead

The researches and progress briefly set forth in this report indicate the trends of the early postwar applications of welding.

In the arc welding field we may expect continuous improvement in electrodes giving greater speeds of welding, improved quality of weld deposit, and the quality of the joint as a whole. The increased use of automatic welding and of various types of gas shielded arcs for "difficult" welding applications in the ferrous and non-ferrous field is a foregone conclusion.

One can also predict a steadily increasing

use of oxygen, acetylene and other gases in welding, cutting and allied processes. This includes considerable uses in operations which have just left the laboratory stage. For example, the advantages of fairly low preheat and postheat treatments in connection with welding and cutting operations are understood by only a small fraction of the welding fraternity. American

genius will find ways of utilizing these laboratory results efficiently and with economy. Pressure welding will become popular in many applications.

The resistance welding industry stands on the threshold of spectacular advances. The use of stored energy and pulsation welding will remove some of the power restrictions and will extend all phases of resistance welding to the joining of heavier parts or assemblies of ferrous and non-

ferrous metals. Metallurgical control with laboratory accuracy will be applied in production where it becomes necessary.

In cooperation with the steel industry the quality of steel for special welding applications, such as low temperature work, will be improved. In turn, these improvements will remove many of the limitations of temperatures and pressures now hampering many process and chemical industries. In the transportation field the aircraft, railroad, automotive and marine industries will share the benefits that come from lighter weights with no reduction in safety.

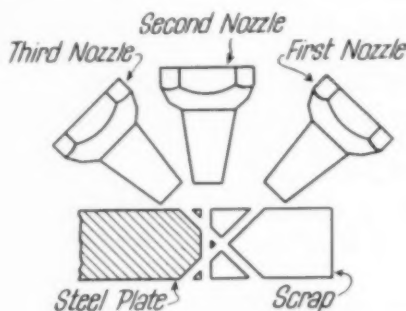


Fig. 8 — Arrangement of Cutting Nozzles for Producing a Triple Bevel on Steel Plate



WELDING

100%

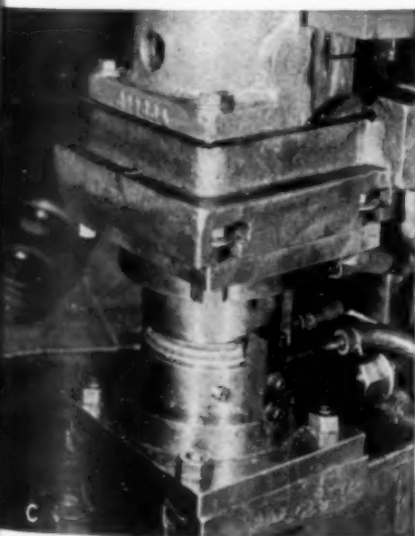


from alloy castings, installed on the standard Federal press welder, and the problem was solved. The new method, producing 1,000 wheel blanks per hour, is shown below in pictures that tell their own story.

Not a revolutionary idea, by any means, but it doubled production on the needed item, and that is typical of resistance welding possibilities throughout the metal working industry. A Federal Press Type Welder such as the one illustrated, or related models in suitable capacities, might have similar application to, let us say . . .

Instrument Assemblies . . . Gauge Cases . . . Electrical Fixture Parts . . . Lock Assemblies . . . Automatic Valve Components . . . Automatic Switch Parts . . . Radio Chassis Components . . . a wide variety of Hardware . . . Ventilator Grilles . . . Speedometer Casings . . . Ash Trays and other Novelties . . . Two Piece Ventilated Container Caps . . . Radio Tube Assemblies . . . Oil Cleaner Assemblies or what have YOU that might be profitably converted to resistance welding if the facts were known . . .

Federal Press Type Resistance Welders (you can spot weld on them, too) are described fully in Federal Bulletin 4520. Write for your copy today. Remember, in resistance welding, the name of authority is FEDERAL.



FEDERAL WELDER CO. 238 Dana Street
WARREN, OHIO

October, 1945; Page 941

VERSATILE MODERN PRODUCTION TOOLS

WELDERS WITHOUT PRIORITIES

Announcement is made by Sales Manager John E. Ponkow, of The Federal Machine and Welder Company, that his company is now in a position to accept unrated orders for resistance welders. While priorities still are all that the name implies, and important war production still is the first obligation, bookings are now being made and delivery dates assigned to a large number of orders outside of the critical category, Mr. Ponkow said. Delivery schedules while far from normal, are improving steadily.

"TAKE THE WELDER TO THE JOB"

In a large sheet metal shop two men were assembling an angle iron framework which was to be the skeleton for a stainless steel kitchen sink and cabinet installation for a large hotel.

"Why don't you spot weld some of that work?" asked a man standing with the shop foreman.

"How the . . . can you horse a bunch of awkward stuff like this through a spot welder?" one of the workers retorted. "And besides, all of our work is special, we don't have enough of any one assembly for that sort of work."

"You don't have to take the job to the welder, I'll show you how to take a spot welder to the job," the visitor said, and proceeded to demonstrate the application of portable, gun-type spot welders to the job. He also proved that they did not need to have long production runs to make this type of automatic resistance welder profitable. The caller was a Federal Welding Application Engineer, and those men now are using a Federal monorail suspended portable welder with a variety of special "guns" that speed up all kinds of sheet metal fabrication in which the shop specializes.

AUTOMATIC STUD WELDER

Welding certain types of lugs and studs to small machine mounts on a production basis sometimes turns out to be a bit of a trick. One solution which has proved a time and money saver is automatic resistance welding. A Federal press-type projection welder with a special fixture and automatic feed was set up for one motor company to produce mounts complete with studs or threaded lugs (set-up interchangeable to meet production schedules) at the rate of 600 per hour.

SPOT AND/OR PROJECTION WELDERS

The difference between spot welding and projection welding, and information on how one Federal resistance welder can be used interchangeably for either method is included in a new bulletin on press-type welders just released by The Federal Machine and Welder. This is one of the most versatile of all types of resistance welders. Title is "Federal Bulletin 4520."

Now! an IMPROVED KENNAMETAL LATHE FILE

- CUTS STEEL NO ORDINARY FILE CAN TOUCH
- PERMITS FILING SPEEDS 3 TO 10 TIMES THOSE POSSIBLE WITH STEEL FILES!
- OUTLASTS MILL CUT FILES 50 TO 200 TIMES



This new Kennametal Lathe File retains all the time- and cost-saving characteristics of previous designs—cuts steel up to 62 Rockwell C hardness; does outstanding job on cast iron and non-ferrous materials; permits filing operations at carbide tool turning speeds; produces superior finish.

And now, in addition, it provides these new features—longer filing surface; quick, easy blade replacement; greater handling convenience.

The filing surface comprises two 4" long Kennametal blanks which have cylindrical nuts brazed to them, and are attached to the aluminum alloy handle by screws. After long service (up to 200 times that obtained from steel files) the blanks can be readily replaced.

The handle grip has a thumb rest and knuckle guard. An extension of the handle beyond the filing surface provides a secure finger hold. A hole in this extension permits the file to be hung up.

On the first production run, a Kennametal Lathe File usually saves its cost many times over. Order one—let it demonstrate to you an astonishingly low filing cost-per-piece.

Features

REPLACEABLE BLANKS

Kennametal blanks are attached by Phillips head screws. Two types are available: fine (30 teeth per inch); and coarse (20 teeth per inch).



LIGHT WEIGHT

Weighs less than one pound. Can be handled with ease, and used for long periods of time with minimum expenditure of energy.



HAND-FITTING GRIP

Handle is comfortable—it fits the hand; provides secure grip. Opposite end of file provides convenient finger hold.



SPECIFICATIONS AND PRICES

COMPLETE FILE		FILE BLANK—2 REQUIRED		
CAT. No.	PRICE EACH	CAT. No.	TEETH/INCH	PRICE EACH
F-45*	\$18.50	F-453	30	\$7.50
		F-452	20	7.50

* Furnished with blanks having 30 teeth/inch unless otherwise specified.

Impact Extrusion*

COLD impact extrusion—the forcing of metal under high pressures through an aperture of different size and contour than the cold metal blank, thereby creating sufficient heat (or force) in the metal to bring it into a plastic state and make it flow—has been used to make collapsible tubes of lead, tin, zinc and other soft metals. Engineers at Douglas Aircraft Co. decided that large savings could be achieved if this process could be applied to aluminum as it would often be possible to produce parts in a single operation that ordinarily require four or five drawing operations. Also, certain parts could doubtless be extruded that cannot be drawn.

A considerable number of parts have now been successfully extruded experimentally and some are being manufactured on a production basis. As an example of the saving, a flanged tube collar cost \$3.37 per piece when produced on regular punch press dies but only \$1.78 when produced by impact extrusion.

Aluminum parts can be cold impact extruded within dimensional tolerances as close as ± 0.001 in., although ± 0.002 in. is more common. Both symmetrical and unsymmetrical parts can be extruded and different wall thicknesses can be obtained. It is possible to extrude an aluminum part to a height of six times the thickness of the original blank.

An advantage of this method is that parts can be made with sharp corners as easily as with round corners. 2S-O, 3S-O or 61S-O aluminum alloys are preferably used although 24S-O can be extruded if it is heated to 200 to 600° F. (but the results are not consistent). Magnesium can be impact extruded if it is first preheated at 700 to 800° F.

Two general types of dies have been developed. In both the metal flows along the punch. Regular impact extrusion dies are made so the metal flows in the opposite direction to the punch movement; since the extruded metal is not confined within the die, the part's outside smoothness is amazing. With the "Hooker process" die, the flow of metal occurs in the direction of the punch movement, for there is an opening in the die that permits

(Continued on page 946)

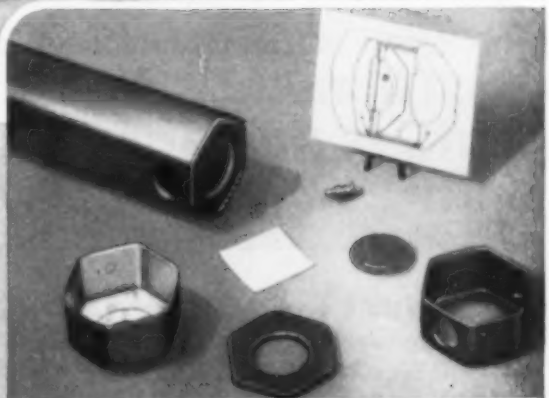
*Abstracted from "Extrusion of Aluminum Parts for Douglas Aircraft", by J. R. Boston, *Machinery*, July 1946, page 139.



HOW THE M-69 IS BRAZED

The steel casing of the M-69 incendiary bomb is an ingenious assembly of the five parts shown in the foreground, inserted into a sheath of hexagonal steel tubing, and copper-brazed in continuous electric furnaces.

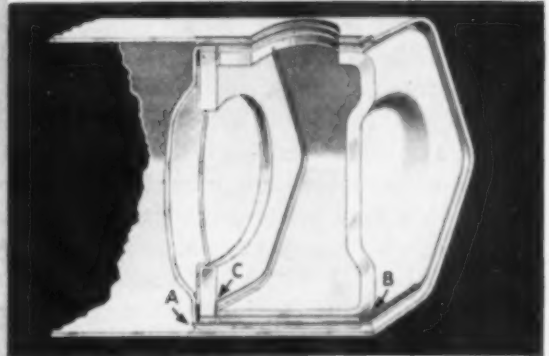
All five parts are made of SAE-1010 steel, and ordinary copper, in any convenient form, is employed as the brazing metal. An asbestos-paper spacer between the steel slug and the washer prevents these members from becoming brazed together.



Capillary Attraction Distributes Brazing Metal

This sectional drawing illustrates the manner in which the brazing metal is drawn up through the uniform, snug joints of the M-69 assembly, by capillary attraction. As the copper lying at point A melts, it creeps longitudinally to point B, where a fillet is formed. It then flows back toward A above the sealing diaphragm until reaching point C, where the nose cup butts against a hexagonal washer $\frac{1}{16}$ in. thick.

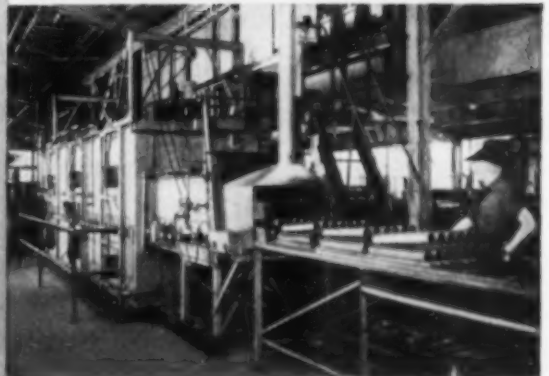
At this junction, the copper creeps up and around the joint by capillary attraction, leaving a fillet at all six sides of the washer. Simultaneously, the copper creeps up through the joints, outside and inside the sealing diaphragm, making a uniform, tight seal completely around the casing.



Typical G-E Roller-hearth Electric Furnace Used in M-69 Brazing

Rated 320 kw, with a heating chamber 17 ft long and a cooling chamber 70 ft long, this furnace is one of many installed specifically for the copper-brazing of M-69 incendiary bombs.

It loads thirty M-69 casing assemblies per tray, double decked and slightly inclined to encourage the flow of brazing metal downward into the joints. The work travels continuously through the heating and cooling chambers and is automatically charged and discharged through the normally closed doors at either end of the furnace.





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You'll want EVERY ADVANTAGE cutting fluids can give you!

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D. A. Stuart Oil Company have been making and applying cutting fluids since 1865—gathering experience that is long, broad and successful—experience that you may use to advantage. Invite a Stuart Oil Engineer into your plant and through him the Stuart Organization will work with you in setting up cutting fluid standards for the top metal-working efficiency you will need for the times to come. No obligation, of course.

The 60-page Stuart booklet, "Cutting Fluids for Better Machining", contains interesting facts about cutting fluids and their application. Write D. A. Stuart Oil Company, Limited, 2743 So. Troy Street, Chicago 23, Illinois.

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Stocks in Principal Metal-Working Centers



Impact Extrusion

(Continued from page 942)

the extruded metal to extend downward. Hooker dies can be made of the progressive type in which the material is first blanked and then extruded in a second station. Less difficulty is encountered with the Hooker die than with the regular type as a true alignment of the punch and die is assured by the tight fit between the two parts and the short sturdy construction of the punch reduces the danger of its failure. Parts with fillets can be more readily produced with the Hooker die.

In the regular type of die, the punch is not well supported side-wise and is sometimes so affected by the pressure of the metal that a noticeable variation occurs in the wall thickness. Therefore, a four-post universal die set was designed to insure true alignment of the punches with dies of the regular type. Adequate punch support is thus provided. The design also lowers die costs and facilitates setups. It is possible to use a Hooker die as well as a regular die in this universal die set.

Aluminum alloys react to impact extrusion entirely differently from other alloys. Under pressures of 90,000 psi., the top and bottom of the blank work-harden and fill up the most minute scratches on the highly polished surface of punch or die. Enough friction is created to hold back the surface skin of the blank while the core of the blank immediately squirts through the die. A pronounced increase in pressure and heat is required to make the skin metal also pass through the die. Any oxide on the surface is likely to be caught in the vortex of the flowing metal, and surface defects from this cause are common. Sometimes the difficulty can be overcome by leaving the bottom of either the punch or die cavity unpolished except for the parts which exert an important influence on the shape of the extruded part; the slight roughness increases the friction on the skin.

The surface at the end of the punch which controls the internal diameter has an important influence on the metal flow and should be highly polished. To limit the friction, it should be full size for only $\frac{1}{8}$ in. and then relieved.

Proper lubrication is necessary and will decrease the required impact force. The lubricant should be of a high flash type and must be

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How Nelson Automatic Stud Welding saves time and material—



Here is a complete fusion weld that is obtained in less than $\frac{1}{2}$ second! Yet the resulting stud weld is stronger than the strength of the stud. By this welding method precision work is obtained economically and close tolerances are held.

Below is a typical example of how Nelson Stud Welding is helping one manufacturer save time and material. Consistent results like this, *automatically* produced, can be obtained wherever studs can be end-welded to metal surfaces.

The equipment for Nelson Stud Welding is handy to use and completely portable — or may be obtained as a single or multi-gun precision jig for close tolerance production of stud welded parts. It is easily operated by men or women, and no previous welding experience is necessary. Workers are securing 1000 or more studs in eight hours without difficulty.

HOW TO DO IT —

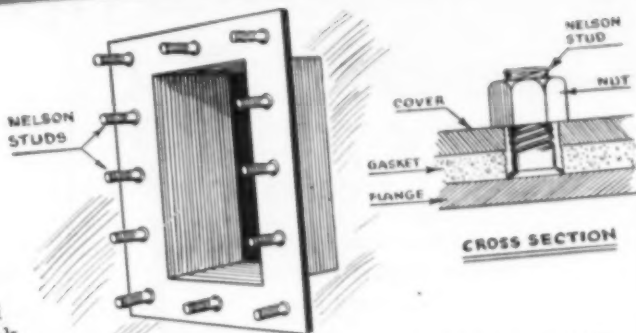
Problem:

SECURING STUDS TO HOLD INTAKE VENT COVERS ON INDUSTRIAL FURNACE.

Former Method--Drill hole through flange, tap hole, insert bolt, and hand-weld head of bolt. Process took too long.

Present Method--Saves more than 40% of the time of former method. Studs are quickly secured with equal strength and accuracy.

After layout and center-punching the studs are welded to the flange. Gasket and sheet metal



cover are then installed on top and secured with nuts.

Portable Nelson "gun" well liked because stud welding can be done on furnace while assembling.

Do you have a problem like this stud welding can solve?

FOR DETAILS AND CATALOG WRITE:

NELSON SPECIALTY
WELDING EQUIPMENT CORPORATION
Dept. M, 440 Peralta Avenue
San Leandro, California

EASTERN REPRESENTATIVE: Camden Stud Welding Corp., 1416 South Sixth Street, Camden, New Jersey

(Continued from page 946)
evenly distributed. The punch is lubricated with tallow or beeswax.

Dies and punches are made of high carbon, high chromium steel hardened to Rockwell C-55 to 57 for the dies and C-58 to 60 for the punches.

Standard inclinable or straight sided punch presses can be used with a capacity ranging from 25 tons for parts with a compressive area up to 0.5 sq. in., to 800 tons for an area of 5 sq. in. Smaller presses may be employed if the aluminum is preheated to 200 to 600° F.

Chip and Tool Temperatures*

WORK done by a metal cutting tool is transformed into heat which is carried away by the tool, workpiece and chips. The horsepower required for drilling as computed from torque and thrust, when compared with that computed from the heat generated during cutting, showed that the calorimetric method gives results in line with those from a well calibrated dynamometer.

Cutting temperatures were measured while machining an annealed low carbon steel. Experimental equipment included a ther-

*Abstracted from "Measurements of Temperatures in Metal Cutting", by A. O. Schmidt, O. W. Boston, and W. W. Gilbert, Preprint (1945) for *Transactions of the American Society of Mechanical Engineers*.

mocouple arrangement in which one element was the tool and the other the workpiece. Observed temperatures increased from 650 to 900° F. between 56 and 115 ft./min. cutting speed (depth of cut, 0.150 in.; feed, 0.030 in.). For cutting speeds between 115 and 320 ft./min., the cutting temperature varied between 900 and 1000° F. The chip temperatures determined from temper colors were almost constant — slightly over 500° F. There is considerable doubt that this method reveals true cutting temperatures.

Calorimeter tests made while machining normalized S.A.E. 1055 in a face mill (depth of cut, 0.125 in.; feed per tooth, 0.008 in.) showed a constant chip temperature of about 780° F. for speeds of 200 to 1200 ft./min. At low speeds

the workpiece and tool conduct away a higher proportion of the heat generated in the chip, because the chip separates comparatively slowly, whereas at higher speeds most of the heat is carried away with the chip and their temperature remains constant because there is more chip material to carry the heat away. The temperature of the tool is much higher at high speeds than at low speeds because the work done per unit time is much greater. The heat in the tool is of the greatest importance because failure is caused by the concentration of intense heat at the cutting edge. The investigation carried on on the calorimetric principle showed that the cutting force for a particular radial rake angle and chip cross-section had approximately the same value for any cutting speed.

In general, if all conditions except cutting speed are kept constant, the temperature of chips of uniform cross-section remains about the same in the high range of cutting speeds, the temperature at the cutting edge of the tool increases with the cutting speed, and the temperature of the workpiece is lower at high speeds.



Darwin

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COBALT CROM

Air-Hardening, Non-Deforming
Cobalt High-Carbon,
High Chromium Steel

A tool steel with an original basic formula of our own specifications. Recognized for long die life and unsurpassed quantity production runs. Outstanding characteristics are simplicity of treatment, uniform hardness penetration to the center, secondary hardness, extremely high tensile strength, resistance to abrasion. Ideal for blanking, drawing, forming, trimming and shearing tools.

FURNISHED IN BAR STOCK, BILLET,
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Metal Cleaning, Finishing, Protection

Process Engineering of Surface

Conditioning and Finish

By George Onksen

*Manager of Industrial Engineering and Service
Solventol Chemical Products, Inc.
Detroit*

ANY LOOK AHEAD, by a man interested in the process engineering of surface conditioning and finishes, must reflect simultaneously a look into the past wartime years. In other words, we must bear in mind that we have recently discovered a lot of ways to treat the old materials, and we have been provided with many new solutions, chemicals, and substances for doing the job—often getting a revolutionary new effect. It was fine that we could do this, of course, for often we had to get along with substitute metals that ten years ago would have been hopeless. If we apply these materials, methods, and information to our postwar problems we may find better ways and means of doing the job, and find this more economical—and of course when we talk about economics we are talking about meeting our competitors.

In manufacturing organizations the responsibility of testing and proving of new materials

and processes for surface finishing and surface coatings before final approval for production varies with different industries. The organization pattern at Guide Lamp Div. of General Motors Corp. under which I have been functioning for the past 16 years is one including the process engineering department which renders constant service to production with reports coming under the supervision of the plant manager or works manager. It will be my purpose first to clarify the function of a modern process engineering department with particular emphasis on surface conditioning of finishes and protective coatings.

While the department at Guide Lamp—a plant normally employing several thousand people—is larger than most, its functions must be assumed by one or more men even in a small firm, if that firm is to be among the leaders in its industry. The relationship of the process engineering department and the purchasing department is one of complete cooperation and continual search for better and more efficient methods and materials. The responsibility for final approval of materials must rest upon the process department, if quality is to be maintained and improved. The relation of the process engineering department to the manufacturing departments is one which renders constant service to production, in the engineering and development of better and more efficient processing methods.

With regard to personnel and special equipment required, assume a large manufacturer of steel stampings and assemblies requiring various types of finish such as baked enamel, lacquers, and electroplate. The personnel of such a department would be a chief process engineer, a layout man, a chemical engineer, a mechanical engineer, an electrical engineer, a tool designer and several service men. The function of the service men is one of trouble shooting, promptly correcting any inefficiencies which might develop in the manufacturing processes. They are usually called on by production supervisors to assist in correcting these difficulties as they appear.

Now the word "assist" is very important. A successful service man encourages a spirit of cooperation between the men in the process engi-

neering department and all of the supervisors throughout the plant.

A staff such as I have described should have a layout room, about 50 by 25 ft. It has a drafting table, layout board, cabinets holding tool engineering layouts and time study records. These records are constantly used when making a progressive layout of equipment for any particular process.

The process laboratory, approximately 50 by 25, should include equipment such as a humidity cabinet, salt spray cabinet, small oven, spray booth, a variable speed lathe, and other essential laboratory equipment. This equipment is used for testing of finished materials before giving final approval for use in production.

I might highlight a few of the problems that such a process engineering department has met and solved in connection with surface finishing operations. One interesting one was to develop a complete process for replacing critical brass, copper and nickel in the manufacture of headlamp reflectors. Many experiments were conducted in finishing a steel reflector surface, trying to duplicate the high reflective surface of brass, silver plated. We were limited to a few materials which were not critical. We finally hit upon the idea of aluminizing a black enameled surface. Success required the development of a new kind of surface structure.

In developing a high quality finish for aluminizing we ran tests to determine a suitable pre-cleaner, a suitable rust resistant coating, and a suitable enamel. We finally decided on one of the newer synthetic organic base liquid cleaners mixed with 30 parts of water in a high pressure spray wash machine. It thoroughly cleaned and temporarily passivated the surface, so that a uniform zinc phosphate coating of fine grain structure free from sparkle and dust could be laid down on it. We followed, then, with two dip coats of enamel for controlled film thickness.

Then came the job of aluminizing this enameled surface, and it took much development work before a suitable fully automatic machine for aluminizing was ready for production. However, this process was developed to such a high degree of automatic production efficiency that I have no doubt but that it will be continued in postwar times.

Surface finishes involve painting. It is a job hardly thought of as a metallurgical job, but more metal parts are shipped painted than with any other kind of protection. Many paint jobs are also done to very close tolerances. Consequently, the problems developed in the control of paint film — its thickness — may be of some

interest to you. My experience with it goes back about ten years.

At one time our process testing laboratory reported to production that parts were 0.0002 in. short of specifications. We thought we had perfect control of all the dip tanks handling these parts. The dip tanks were, in fact, under control as far as filtration, agitation, and circulation were concerned. Specifically, the tanks contained 1200 gal. of enamel, with a 100-gal. replenishing tank attached. An agitator was located in the bottom of the tank, mechanically operated, which prevented pigment from settling. The circulating system, pumping 600 gal. per hr. from the bottom of the tank, prevented concentration of pigment at any place in the system. The filtering and circulating systems filtered out all foreign or coagulated matter. A surface agitator prevented an oxide film on the liquid. The viscosity of the enamel was maintained at 20 sec., using a No. 4 orifice at room temperature. The surface film thickness was measured by dip coating a piece of clean glass in the same enamel at different temperatures, always maintained at 27 viscosity (using No. 4 orifice) by proper amount of thinner.

A series of such tests at various temperatures proved that, to maintain specified film thickness, the temperature as well as the viscosity must be controlled. We therefore placed a heat exchanger in the circulating system which heated the enamel as it passed through. The exchanger



was arranged with automatic control so that a rise of one degree temperature per hour was the maximum permitted. Heating the enamel has since proved to be a very simple and effective method of meeting the specification of film thickness for all jobs.

While on the subject of temperature it might be advisable to stress the importance of other temperature controls—especially temperatures in continuous ovens. Basic information can readily be had by passing a portable recording thermometer through the oven in an insulated container suspended on one of the conveyer bars or monorail. The gas-filled bulb will of course be exposed to the temperature of the oven. This, as it travels through on the conveyer, will record a temperature curve along the length of the oven. If found necessary, adjustments can then be made to the best point in the oven to improve the oven temperature curve. By having the true temperature curve of an oven, we can materially assist the paint manufacturer in formulating enamels which will suit the existing conditions.

Another problem with which we have had some considerable experience is the cleaning or removing of solidified compounds from polished or scale-free parts including reflectors, stampings, and automobile hardware, prior to electroplating. By putting the parts immediately after buffing on a plating rack and passing them through a solution of synthetic organic base liquid reduced with water, and heating them to 200° F. for approximately 1 min., the binder in the compound is reduced and the solids completely removed in a pressure spray of the same material as used in the dip tank. The parts coming from the solution are thoroughly clean and bright and the surface has not been activated. We believe this is a simple solution to an important problem that has been troubling us for years.

Looking into the future, I believe we are headed for a period of greater acceleration in process engineering than we have seen in the past—especially in that branch of it which relates to the various operations involved in an adequate process for surface cleaning and protection. The acceleration we have witnessed during this war, based on engineering chemistry and metallurgical control of devices, leads us to believe that we must tighten our belts and do a little more work with new and better and more economical methods in processing and manufacture. Especially is it desirable, as indicated in some of the above remarks, to pay attention to the *cleaning* of the metal or other surface, to its preparation for receiving the final coating that meets the eye and resists the weather.

Blast Cleaning of Metal

By A. L. Gardner
Pangborn Corporation
Hagerstown, Maryland

INDUSTRIAL blast cleaning is a mechanical process for economically and quickly treating and cleaning the flat, irregular, raised or depressed surfaces of any metal or processed material by subjecting such material to a bombardment of hard granulated particles called abrasives.

Quoting from a paper read over 40 years ago by F. B. Brooksbank, the well-known pioneer in many of the present blast cleaning processes: "Abrasive particles act much in the same manner, but to a greatly reduced scale, as artillery projectiles in breaching a masonry wall, each grain independently of all the others. How abrasive is given velocity, how work is presented to the blast are matters of indifference when examining the theory of the process. As the total action of the blast is but the sum of the action of the individual grains, so the action of individual grains is to be considered."

Now let's analyze the action of one of these abrasive grains in order to understand the action of the complete blast. Under average working conditions the particle strikes the work's surface while traveling at a velocity of 250 ft. per sec. If the angle of impact approaches 90°, the imprint or mark upon the surface is roughly the same shape as the abrasive particle. If the angle of impact approaches 45°, the imprint on the work surface is roughly the shape of the forward edge of the abrasive particle, somewhat like the shape of a teardrop—but, due to the angular impact, the imprint is shallower than when impacted at 90°. In actual practice of barrel cleaning or table cleaning the work surface is in motion; therefore millions of abrasive grains strike the work surface per minute from all angles and any scale or burnt sand on the surface is very rapidly pulverized, and the metal is given a uniform and pleasing matte finish. Enlarged cross-sections through the work show these imprints as indentations and ridges overlapping in all directions with many of the ridges slightly undercut in varying directions. These irregular contours and undercuts provide positive anchors for priming coats and other surface applications.

Blast cleaning by abrasive operation is

neither a cutting, a grinding or an abrading process in the presently accepted meaning of these terms. It is essentially a battering, a pounding, or a bombardment of the work surface by the successive impacts of countless individual projectiles — grains of abrasive which are usually sand, or steel, or some of the boron compounds from the electric furnace.

In all modern blast cleaning the number of abrasive grains allowed to strike the work surface may be regulated from small to great amounts. For all average cleaning problems the standard airless centrifugal wheel — the unit which throws abrasive against the work surface by centrifugal force — handles an average of 400 lb. of steel abrasive per min. Divide by 60 and we see that $6\frac{2}{3}$ lb. of abrasive is handled every second. As steel abrasive weighs 275 lb. per cu.ft., we find each pound of abrasive bulks to 6.28 cu.in., and

the $6\frac{2}{3}$ lb. of abrasive handled in the centrifugal wheel amounts to 43 cu.in. of material per sec. As our steel abrasive grain averages $\frac{1}{32}$ in. in diameter it follows that there are 33,000 particles in each cu.in., and that each second the machine operates approximately 1,400,000 particles have struck the work — and that for each minute approximately 84,000,000 particles. Consider: 84,000,000 times the impact imprint of each particle of abrasive we first considered! Where a greater number of impacts are required multiples of these wheels are used for one machine.

On the blasted surfaces, the depth of indentation is determined by the velocity of the particle and its grain size. (We understand how the *shape* of the indentation is largely governed by the impact angle.) The velocity of abrasive travel varies according to the speed of the centrifugal wheel or, in the nozzle blast, to the air pressure

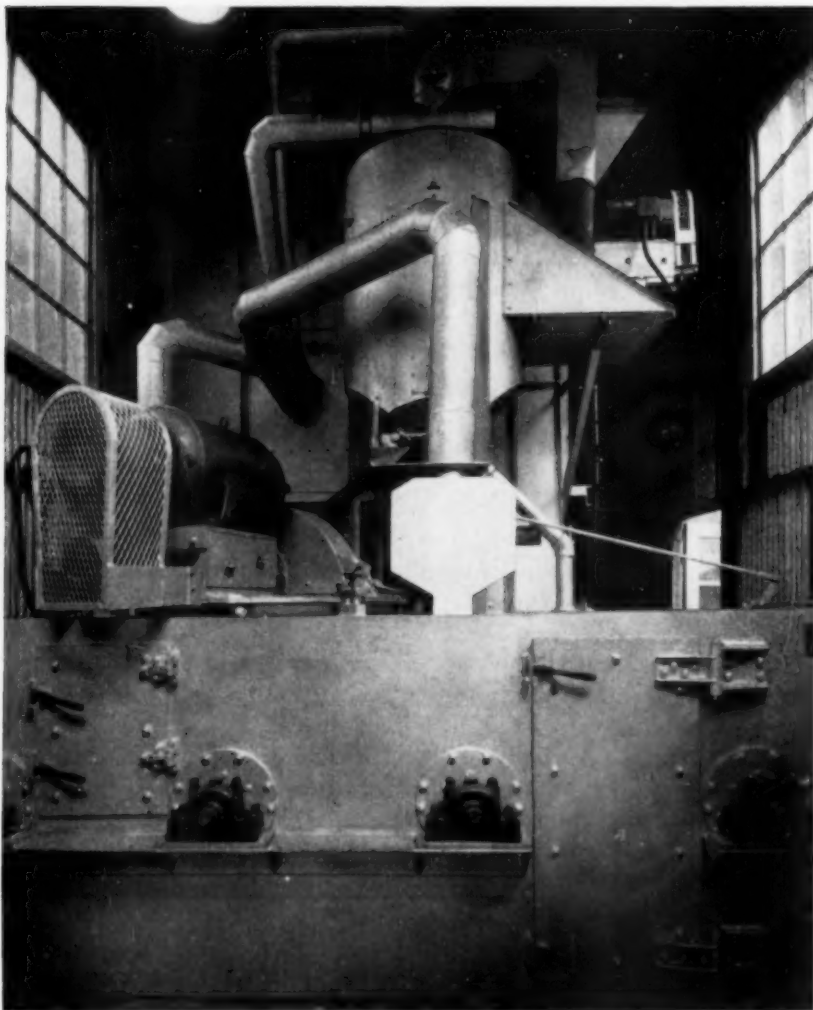
used. This speed must be limited to the ability of the abrasive to withstand the shock of impact. The most useful velocity for abrasive from a centrifugal wheel is 250 ft. per sec. Using steel abrasive and compressed air at 80 psi. the velocity is also approximately 250 ft. per sec. For sand, due to its lower specific gravity, the velocity is approximately 275 ft. per sec.

The variation in velocity when using compressed air is due to the compressibility of the air, and the shape, size and specific gravity of the particles. The centrifugal wheel furnishes a positive means of acceleration, so the above variables are not present, and any kind of abrasive may be continuously projected at the same velocity.

Blast cleaning is entirely a mechanical process and can be used regardless of surface shapes or surface indentations, and will give approximately the same conditions of finish notwithstanding any irregularities of surface. By choosing the size of the abrasive grains, the velocity of the grains, and the angles of impact, types of finishes can be obtained varying all the way from a smooth satin finish to a rough pebble finish.

The blasting of metal sur-

Shot Blasting of Round Bars at Bethlehem Steel Co.'s Mill Is an Automatic, Dust-Free Operation. Bars go through the protective casing on rollers set at an angle so the bars themselves rotate while they are exposed to the blast



faces does not produce surface embrittlement but imposes within such surfaces a state of compression. On this fact is based the ability to improve the fatigue resistance of metal parts by shot blast peening of their surface.

In equipment designed to handle the work, the blast cleaning process is used for removing sand or scale from sand cast metals, for removing scale from heat treated metal, for preparing metal surfaces for enamel, galvanizing or metal spray coatings. It is also used in the monumental field for lettering on stone, and in the ceramic field for etching designs on glassware.

Within the past few years the demands for unparalleled war production have produced many special automatic or conveyer-line blast cleaning installations, both airless and air blast. These automatics, with their superb work handling, have very greatly reduced the labor cost of handling awkward pieces, and have eliminated dust problems so that blast cleaning, once considered as a hazardous, costly and dirty operation, has cleaned its own skirts and is today taking its rightful place as a modern efficient tool, mechanically producing ultra-clean surfaces of uniform quality.

Surface Preparation of Cast Iron

By J. H. Shoemaker
President, Kolene Corp.
Detroit

ASUBJECT such as this has numerous ramifications, and would include various mechanical processes. However, I will confine myself to a specific chemical process which has been successfully practiced for some years. It stems from the thought that even a freshly machined piece of gray cast iron of good commercial quality has, as normal microstructural ingredients, substances such as graphite, iron carbide, and phosphide, sulphide or slag particles. The casting, if unmachined, may also have sand from the molds, rust, grease or other organic dirt. Mechanical operations can remove the latter, but the basic requirements for preparing a cast iron surface for a bond with protective coatings are to remove not only the surface impurities but also those natural

ingredients of the iron itself that interfere with the coating or its bonding. Once this is done, and a surface prepared which is substantially pure ferrite — nothing but microcrystals of iron itself — then the surface itself has a superior resistance to liquid corrosion, simply because there is no longer a multitude of tiny electrochemical cells operating to start up galvanic action. Again, if the coating is to be a metal coating, an alloying action at the surface is desirable, if not in fact necessary, and it is far easier to set up conditions for thorough alloying with a pure iron surface than with the heterogeneous structure of normal cast iron.

The so-called "Kolene" process, therefore, was devised to remove everything but the iron from a casting's surface by alternating oxidation and reduction cycles. The installation is simple. The process uses a molten salt bath contained in a welded boiler plate pot or any other suitable construction. The bath melts at about 500° F. and is activated with 6 volts of electric current. One lead from a direct current source is connected to the pot, the other to the work or to the fixture or basket holding the work. At first the current is applied with the work being the cathode; reduction reactions then occur in the vicinity of the work which reduce the scale or rust at the surface, and loosen the sand and other inert materials embedded therein. Then by reversing the polarity by throwing a double-throw switch, the work is made the anode; oxidation reactions then occur which remove those oxidizable impurities exposed in the bare metal surface, such as sulphur, phosphorus, carbon, graphite. This will also form an adherent iron oxide, of course, but it is a different oxide from the scale that was on the casting originally. Finally, by switching back to the reduction cycle, the iron oxide is removed, leaving a substantially pure ferrite surface.

Another method was described briefly by T. E. Eagan, chief metallurgist of Cooper-Bessemer Corp., in "Bits and Pieces" in *Metal Progress* for August. His firm uses it primarily to prepare cast iron bearing backs for babbitting, and he gives it the high praise of saying that a "chemical bond with the babbitt could not be made — to my belief — until this process was introduced".

In the form he uses it for preparing bearing shells, the process requires two baths of proprietary chemicals. One bath is a molten salt bath which runs between 760 and 800° F. This is a very highly oxidizing bath and puts a coating of oxide on the surface. It burns out some graphite flakes on the surface of the cast iron, and also has a tendency to decarburize steely parts of the microstructure. The metal as it comes out of

this bath has a dark or black tone. It is then rinsed and placed in the second bath, which is a highly alkaline, ammoniacal water solution, that dissolves off this oxide. The shell is again rinsed and given a very quick dip in a cold 10% hydrochloric acid which neutralizes any remaining alkali. Without further rinsing, the metal is ready for tinning and babbitting, and so is placed into zinc chloride liquid flux, and then into the tinning bath.

Microscopic examination of cast iron parts after various stages in the process bears out the facts above stated. For example, a cross-section through a cleaned gray iron that has a hot-dipped tin coating shows that the graphitic carbon has been removed to a depth of approximately 0.0025 in. The "tinning" metal, with its low surface tension, has penetrated into the apertures from which the graphitic carbon has been removed, and these act in place of the grooves, dovetails or anchor holes that would otherwise be necessary to give the tin or babbitt a secure hold on the cast iron. Babbitt linings have been cut from $\frac{3}{8}$ in. thick — necessary for mechanical bonding — to $\frac{1}{16}$ in. thick, which is ample for actual anti-friction functioning, and this represents on the aggregate an important saving in tin, even yet our scarcest metal.

Another instance of saving in strategic metals will not only stress the importance of proper surface before electroplating or dip coat-

ing, but also represent the type of conversion that will persist postwar, in all likelihood.

Inlets and outlets for radiators previously were made of bronze, and later of malleable iron so that they could be tinned for a combination of corrosion resistance and soldering ability. While malleable ordinarily has little or no graphite at its surface, on certain machined areas you would have exposed graphitic carbon and on unmachined surfaces you have the vestiges of scale and sand that would make it difficult to attach a firm coating. Going all the way at once, and substituting gray iron for the more expensive malleable, the gray iron castings after having been processed are dipped in an alloy low in tin and high in lead, and thus made ready for soldering with the new solders (also forced on us by the tin shortage).

Similar problems arise in the brazing of joints between dissimilar iron alloys, such as steel tubing to cast or malleable iron fittings. It does no good to over-pickle these parts, for the carbon released merely smuts the surface, and the smudge is almost impossible to remove by old-time methods. With surfaces on both steel and iron prepared to fresh ferrite crystals and nothing else, soldering or brazing becomes very easy indeed, even with the new solders that contain almost no tin.

Electroplating of nickel or zinc on prepared cast iron is not only feasible but commercial.

Improvements in Zinc and Nickel Coatings

OF THE TWO favorite metals offering sacrificial corrosion protection to iron and steel, namely, cadmium and zinc, cadmium was preferred in the prewar period despite higher metal costs because of its ease of application, general familiarity with the cadmium plating process, its superior appearance and reputedly higher protective value. With war came a shortage in cadmium and the necessity of changing to another metal, which was naturally zinc.

A great deal has been learned about zinc plating during the intervening four years, and much of it has been learned the hard way, as many platers can attest. I am going to mention a few of the factors involved, and try to show how many of the objections to zinc deposits and the zinc plating process have been avoided, minimized, or overcome.

In the first place, *brightness* was not consid-

ered a requisite for most zinc plated ordnance parts because, after all, corrosion protection was what was required primarily. But it was soon found that inspection was much easier if the coatings were bright, and after an inspector had once seen a bright coating, he rejected anything that wasn't bright! As a matter of fact, lustrous coatings do not stain or watermark as readily as dull deposits. Some of the subsequent treatments, that is, chemical film treatments, gave trouble when placed on certain bright zinc deposits, so those solutions had to be modified to produce

By Myron B. Diggin
Chief Chemist

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semi-bright or full-bright deposits with good physical characteristics.

In changing from cadmium to zinc plating, users found immediately that zinc does not have cadmium's ability to deposit over a small amount of scale or heat oxide, nor does it deposit as well on gray iron or malleable iron castings. Improved cleaning and pickling processes have, in a large measure, overcome these shortcomings. I would say that about 90% of the castings encountered can be successfully coated with zinc by modifying the solution, the operating technique, and also — what is more important — going back and doing a real job on the initial cleaning of the castings.

Zinc plating solutions are more sensitive to the heavy metal impurities, but now that it is recognized that bright plating solutions must be pure, effective methods have been developed for removing both inorganic and organic impurities. This includes new filtration equipment, filtration aids, activated carbons for purification, addition of zinc dust, and sulphide treatments for removing heavy metal impurities. As a result an alkaline solution of zinc can now be operated indefinitely by taking these precautions — and on iron castings, too, something that technical literature of a previous decade would say is impossible.

Another striking difference between cadmium and zinc is the way the anodes corrode in the plating tank. In cadmium solutions the anodes corrode satisfactorily even though the temperature, concentration, and current density vary considerably. The effects of irregular anode corrosion, if obtained, were not very serious. Zinc, however, is exceedingly active in alkaline solutions; it has appreciable chemical solubility, and particles released from the anode would

migrate over to the cathode and produce rough spots. Alloy anodes have been developed by several manufacturers to take care of this condition, yet even with those alloy anodes, troubles were experienced in the beginning. Electroplaters soon found out that the control of anode current density was important, much as it is in alkaline tin plating. So they used the proper anode current density and eliminated a great deal of the roughness at the cathode. Then bags made of a synthetic resin were used to cover the anodes. They also learned how to purify the solution continually, because some of the heavy metals will

deposit on the anode. A patent has been issued recently describing the application of a small counter-current to balance anode and cathode efficiencies and thus to prevent the build-up of metal in solution.

The speed of plating in an alkaline zinc solution is much higher and the current density range less critical than in cadmium solutions. Current densities in zinc solutions are generally higher than those in cadmium solutions. During the war they have been upped considerably. It would be foolish to set a limit because next week someone will go a little higher.

The throwing power of zinc solutions was supposed to be very poor, and that was the reason why cadmium was chosen for many applications. It has been raised to where it is comparable with cadmium by control of solution composition and operating conditions, especially the temperature of the bath. A process using superimposed alternating current upon the normal direct current in a special electrolyte appears to be beneficial in some applications in respect to rate of deposition and throwing power.

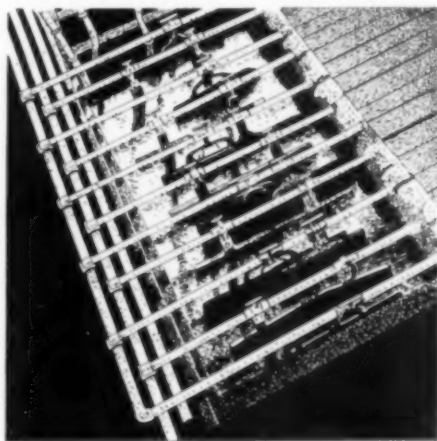
When zinc plating very complicated objects it may be desirable to use insoluble anodes, taking the zinc from the solution. This is a rather delicate operation, for the solution loses zinc very rapidly, and *pure* solutions had to be continually added, purified so that damaging impurities do not build up in the solution.

In regard to the protective ability, it has been demonstrated that equal thicknesses of zinc and cadmium applied to steel give equivalent protection in atmospheric corrosion tests — provided the zinc deposit is pure zinc. For some special applications, cadmium is preferable, but on the other

hand in locations where sulphur fumes are prevalent, zinc is somewhat superior as a protection.

Objections to zinc coatings, because of the tendency for bulky white corrosion products to be formed on the surface when the coated parts are in an environment that is highly humid or in contact with stagnant water, have been overcome by the application of chromate films. A number of such treatment processes are available, both immersion and electrolytic, and are being employed at an ever-increasing rate.

Improvements have also been made in acid and ammoniacal zinc plating solutions — the type

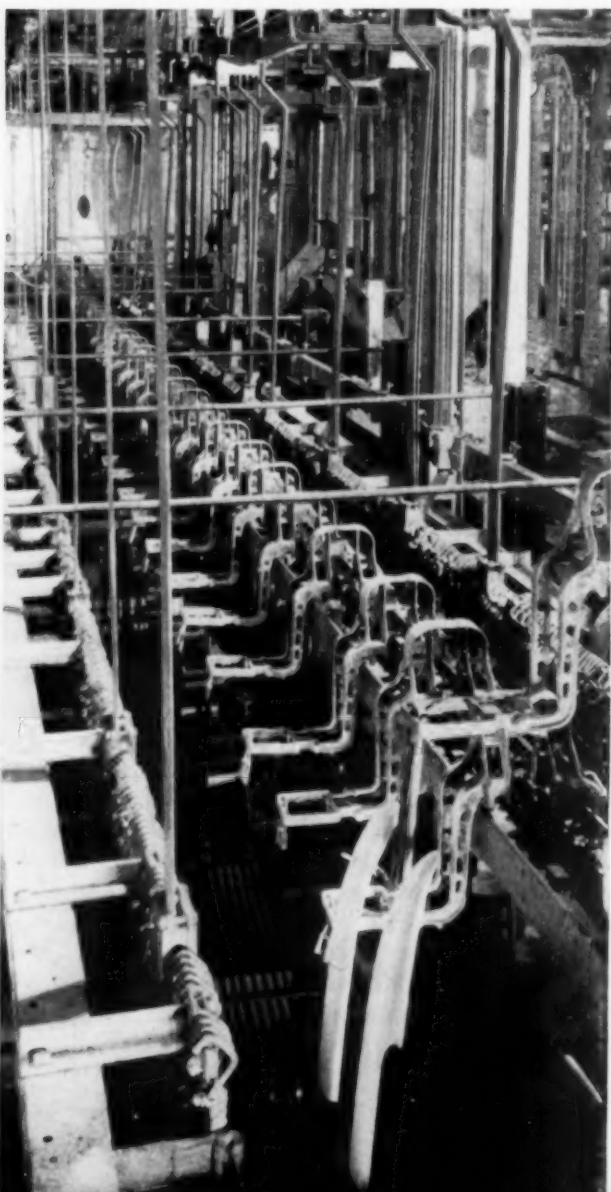


of solutions used on large scale production of sheet, strip and wire. Electrolytes have been developed with low electrical resistivity and high deposition rate. New installations are being made for large scale zinc plating with insoluble anodes, obtaining the metal from ore and waste products such as sal-ammoniac skimmings or other industrial residues. Improvements have and are being made in equipment for zinc plating in mass production, resulting in lower maintenance and overall production costs, greater uniformity of product and better physical characteristics of the deposits. Zinc coatings, properly electrodeposited on steel wire and sheet, have quite remarkable properties that fit them for many exacting uses.

In designing for the peacetime world of tomorrow, where will zinc plate stand?

For plating fabricated articles, many of the smaller plants and jobbing shops using manual

Peacetime Brings a Return to Mass Production of Nickel Plated Automobile Bumpers. This tank at Standard Steel Spring Co. is 67 ft. long, 8 ft. deep



equipment will return to cadmium plating despite higher metal costs because of ease of control of the process. Many larger concerns having automatic equipment and good technical control will take advantage of the experience gained with zinc plating during the war period, and use the cheaper zinc coating, with or without subsequent surface treatments, and will turn out a consistently good product.

A large tonnage of steel will be plated at the source — that is, in steel mills, and will be used for consumers' goods. Refrigerator boxes, for example, can be stamped from steel stock which has been zinc plated and phosphate treated and, after fabricating, sprayed with a synthetic resin enamel. Composite coatings of this nature, properly applied, will give excellent service in either temperate or tropic zones. Zinc plated steel, without subsequent coatings, will be used to a large extent on goods which were formerly unplated. Raw edges are protected electrochemically and the protective value can be further enhanced by chemical film treatment.

Electrodeposited Nickel

The technique of nickel plating has progressed beyond the place where the plater used an "all-purpose" solution. The war emergency accelerated the study of the physical properties of all electrodeposited coatings including nickel. For many military purposes it has not been sufficient merely to deposit nickel, copper, zinc, tin or some other metal under ordinary conditions in conventional electrolytes. Plating solutions, operating conditions and plating cycles have had to be modified to produce deposits of predetermined physical properties. These improvements, coupled with the advances made since the advent of the bright nickel plating procedure several years ago, will re-establish nickel plating as one of the most important coatings for consumers' goods.

Many of the early solutions designed for bright nickel deposits produced porous layers low in protective value. Deposits also had high internal stress caused by simultaneous deposition of organic brighteners. Cracking, peeling and lifting from the base metal were not uncommon. Some of the solutions lacked the stability necessary for uniform production. Cost of operating, despite the saving in buffing costs, was high. The cobalt-nickel semi-bright and bright plating solutions, containing organic compounds of low molecular weight for buffers and depolarizing agents, are now being used extensively because of the hardness of the deposit, its pleasing blue-white color, and its relatively high ductility in

relation to hardness. Atmospheric corrosion tests have shown that these alloy deposits are more protective than deposits produced from standard nickel solutions.

For example, an 18% cobalt-nickel deposit can be produced with a hardness of 600 Vickers. A 1% cobalt-nickel alloy will have a hardness ranging from 370 to 500 Vickers depending upon the pH value of the solution. In comparison, the standard Watts bath produces dull-gray deposits with a Vickers hardness of approximately 220.

These improved bright nickel processes will be available, now that the war is over, for articles in civilian consumption. The physical properties of the deposit produced in these processes will be critically evaluated by prospective purchasers who will be better able to match characteristics with their requirements from experience gained during wartime.

For specification plating on mass produced articles requiring heavy and highly protective deposits such as automotive parts, it is probable that softer semi-bright nickel coatings will be used as an undercoating for chromium. It should be remembered that semi-bright plating solutions produce deposits with good physical characteristics. They can be buffed easily, and the nickel can be applied at a faster rate than conventional nickel deposits. Racking and solution maintenance will be less critical, and the results will be more uniform than when an attempt is made to produce fully bright deposits from a solution containing a number of organic chemicals.

A new semi-bright nickel plating process was announced recently. The bath is simple in composition, containing only two chemicals—nickel chloride and nickel acetate. No conductivity salts or organic addition agents are employed. Deposits from this solution are moderately hard (Vickers 370 to 380), and have an elongation of 8 to 10% in $\frac{1}{2}$ in. and 6 to 7% in 1 in. A cross-section of the deposit viewed under high magnification shows a typically structureless appearance of a hard nickel deposit. A true semi-bright finish is obtained in thicknesses up to 0.002 in. This process has been used for building up worn ordnance parts with nickel thicknesses ranging from 0.01 to 0.20 in. It can also be used for nickel plating steel for cladding and rolling, for nickel plating stereotypes and electrotypes, and for electroforming. Another use is for nickel plating formed articles; simplicity of tank operation and good physical characteristics of the deposit will give it preference over ordinary or bright nickel baths.

Two processes combining nickel and zinc should be mentioned, as these coatings may have

considerable use postwar. In the first process nickel is first deposited and then zinc; the composite is heat treated to alloy the nickel and zinc. It is claimed that this coating will withstand a long salt fog test. It is a dull-gray color, which precludes its use on many consumers' goods.

The other deposit is a nickel-iron alloy. It is said to be silver white, and to all intents and purposes, a bright deposit. The alloy is harder than either electrodeposited nickel or iron and the tensile strength is also much higher. The deposit is slightly anodic to steel, which makes it an interesting coating for protective purposes. It is claimed that as little as 0.0001 in. of deposit has withstood a six-months' outdoor exposure with no attack to the base metal and that 0.00025 in. will withstand a year of normal exposure. The developers of the process suggest that the alloy, when plated with tin and heat treated, gives superior resistance to corrosive influences than hot dipped tin or electroplated tin. The solution is stable in operation and can be operated at high current densities with high efficiency.

Improvements in Other Protective Metallic Plates

By R. B. Saltonstall
Technical Director
The Udylite Corp., Detroit

UNDER THE HEADING "Protective Metallic Plate", we have two separate classifications—protection against chemical and electrochemical corrosion, and protection against wear.

In the first class, there are the coatings which are anodic to iron, such as cadmium and zinc, and the various non-anodic coatings and borderline cases, like copper, nickel, tin, lead, silver, and the rare metals. In the second class are coatings which are applied for protection against physical wear and for lubrication, such as chromium, nickel, copper and the composite coatings of silver, lead, and indium used for bearings.

I believe the greatest general improvement in the first class of metallic coatings, and one that will undoubtedly have much attention in

peacetime practices, comes from an increased consciousness of the importance of minimum thickness specifications, and the development of practical and economical ways and means to meet such specifications. The importance of process control has been emphasized. The limitations of electroplating processes, especially with regard to distribution of deposit on articles of irregular shape, have been realized as never before. Various methods of racking, together with properly placed auxiliary anodes, have been utilized to overcome these limitations. Industrial buyers of electroplated coatings in the postwar period will find it to their advantage to continue to emphasize and impose specifications which prevent the shipment of parts that look good, but have nothing but a "flash" on certain areas.

Prewar, the automobile manufacturers led the field in demanding heavier electrodeposits of nickel (or copper and nickel) to prevent rusting of steel parts. It is now evident that this trend will continue postwar. All you need to do is to look at the bumpers, grill guards and other exterior hardware on the cars now running around on the streets and which have been in service for several years, to understand why electrodeposits two to three times as heavy as specified in the past will be demanded in the future. New high speed bright copper plating processes have been developed, and it is anticipated that high speed bright nickel plating solutions will soon be made available.

We have learned a good deal about how to make heavy deposits. Generally speaking, the thicker the deposit, the better is the protection against corrosion yet the more difficult it is to make. The lessons we have learned regarding filtration of solutions, purity of solutions and increased speed of plating will be valuable in the future.

Cadmium has been a critical material, the demand for the military considerably exceeding the supply. In order to spread the available metal as far as possible, many thickness specifications have been revised downward. Existing methods, with precautions as to clarity and purity of solutions, proved adequate. Zinc, much more plentiful than cadmium, was frequently substituted (as noted in the article by Dr. Diggin).

There has been an increased interest in the use of electrodeposited lead as a protective coating. Surprisingly good protection is afforded by lead coatings 0.001 in. thick. One new lead plating solution has been introduced and another type has been made available commercially as a liquid concentrate. The limited ability of these solutions to plate in deep recesses — as compared

to that of alkaline cadmium, zinc and tin solutions — plus the rather unattractive appearance of lead will probably confine it to special applications where eye appeal is of little importance, or to use as an under-plate.

As a conservation measure, there has been a great increase in the electrodeposition of tin on steel strip, especially tinplate for the manufacture of tin cans. Newly devised solutions for this special application, together with the engineering of special equipment of great interest and reliability, have resulted in plating speeds heretofore unattainable.

So far, these remarks have been confined to protection against atmospheric corrosion. There is another type of surface reaction which is desirable on certain areas of steel parts and highly undesirable on other areas of the same parts. I refer to the reaction which takes place in carburizing and nitriding furnaces. It has long been known that a good coating of copper on steel will prevent carburization of the underlying surface. In the selective carburizing of aircraft gears and other machine parts it has more recently been shown that the *smoothness* of the base metal is an important factor in depositing a copper coating of reasonable thickness, sufficiently impervious to the carburizing gases. Various techniques of masking certain areas have been developed, using lacquers, waxes, and rubber and plastic masks or sleeves. Sometimes the entire article is copper plated and the copper is then machined off the areas to be carburized.

Most of these remarks about carburizing apply also to nitriding, except that electroplated tin has been commonly used for preventing nitriding on certain areas. Tin, being a rather fusible metal, melts in the nitriding furnace, spreading out or dropping onto areas intentionally left bare, and causing soft spots on these surfaces. What promises to be a satisfactory solution to this problem is the use of an electrodeposited bronze which has a higher melting point than tin and affords excellent protection against the penetration of nitriding gases.

So much for improvements in metallic plate for protection against corrosion and chemical reaction. We will now discuss briefly improvements in plate for engineering uses, such as resistance to wear, salvaging of worn parts and other special applications.

Electrolytically deposited chromium has enjoyed a tremendous increase in use in this field, largely because of its great hardness and unique surface properties. The advantages of chromium plating machine tools, gages and dies were well known prior to the war, but because these

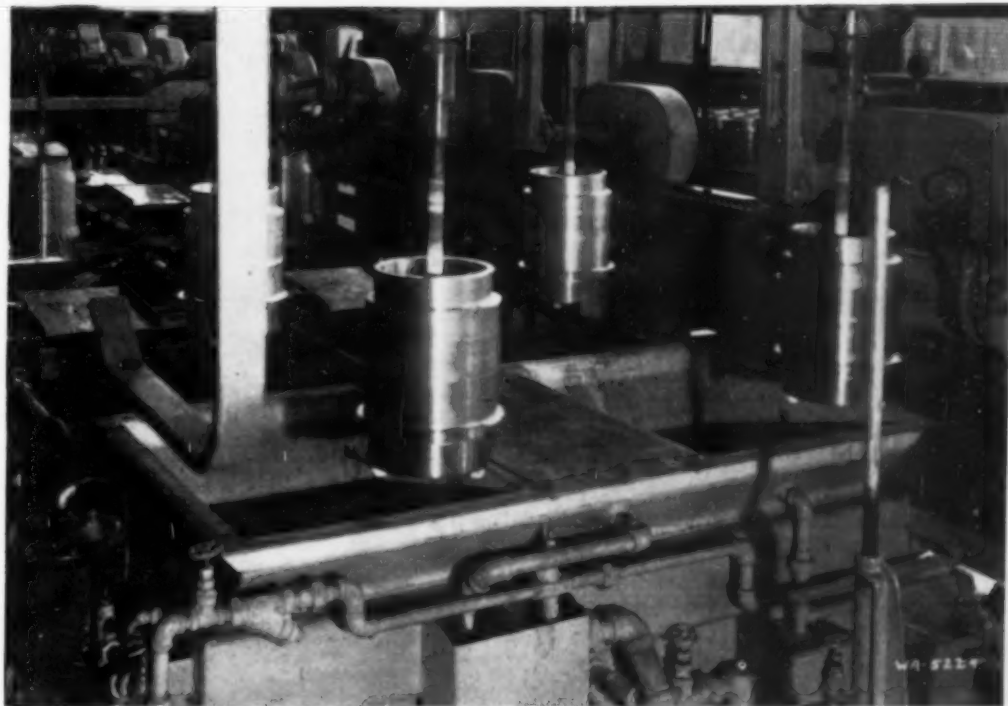
toolroom supplies were easily obtainable when worn out, many purchasers failed to utilize the advantages of the improved designs. However, when an undersized or oversized tool, die or punch meant serious production delays, many manufacturers were forced to chromium plating these parts, and incidentally found that they prolonged, in many cases almost indefinitely, the life of the parts plated, increased the accuracy with which the tool could be ground, and at the same time improved the tolerances on the final product.

A modification of this principle is the chromium plating of worn internal cylinder walls of aircraft engines for salvage, and the chromium plating of aircraft piston rings and cylinder walls of new diesel engines. Because of the reluctance of a smooth chromium coating to retain a film of oil the surface is etched and honed. This procedure results in a smooth surface, covered with a network of minute indentations which hold the oil. Another process lays down a porous plate, for the same purpose.

A very valuable publication concerning all phases of the process is "Chromium Plating", a 70-page mimeographed pamphlet issued in 1943 by the War Metallurgy Committee of the National Research Council in Washington.

Another application of metallic plate for the protection of punches and dies is the coating, not of the dies but of the steel to be drawn through the dies, with a film of copper, zinc or lead. Copper has been applied both electrolytically and by immersion deposition for this purpose; zinc by electrodeposition, and lead by hot dipping. These metals act as lubricants, promoting very deep draws and thus minimizing the number of draws necessary.

A relatively new but extremely important development is the manufacture of aircraft engine bearings by electrodeposition. A steel base is plated with a very heavy coating of silver, often 0.050 in. thick, the silver is then machined 0.001 to 0.0015 in. undersize, and accurately built up



Loading End of an Automatic Tin Plating Machine, Preparing Cyclone Cylinder Barrels for Selective Nitriding. (Wright Aeronautical Corp.)

to size by lead plating, followed by a flash coating of indium which is later diffused into the surface of the lead by mild heating. Electrotin has been used instead of the indium and in some cases an electrodeposited alloy of lead and tin is placed over the silver. The extent to which this development will find use in the postwar era is at present problematical, but there is no reason to doubt but that a bearing that has been found to have superior reliability in such an important place as an airplane engine will also be specified for operation in peacetime machinery requiring the utmost reliability.

This discussion would not be complete without mention of plated coatings on plastics and aluminum. Plating metallic coatings on plastic radio antennae for conductivity and plating on plastic safety helmets for heat reflectivity are two practical examples. Aluminum crankshaft plugs are being nickel plated to prevent chewing of the soft aluminum surface by the harder crankshaft metal at the juncture. Millions of plastic buttons for military uniforms have been heavily copper plated in bulk, burnished to brighten and finished by silver or gold plating. Proprietary processes are available for preparing these materials for plating. Adhesion of the initial electrodeposit to the base material is frequently inadequate; undoubtedly this feature will receive attention and be corrected.

Oxide Finishes on Copper, Steel and Aluminum

By Walter R. Meyer


Technical Director

The Enthone Co.

New Haven, Conn.

OXIDE COATINGS have been rather widely used in the war years for many purposes, and they will doubtless be continued in peacetime, for they have a definite place in economical production. Their chief uses are for a limited degree of rust protection, for the heat radiating characteristics of a black surface, for contrast coloring and identification, and in the finishing of certain parts where the finish must not break or where the tolerance is very close.

The type of coating as produced on steel is an oxide coating, a ferrous-ferric oxide, very adherent to the base metal but rather thin. The thicknesses range from 0.00005 to 0.0001 in., with some penetration in the grain boundaries. As just mentioned, the corrosion protection is not very great, ordnance specifications usually calling for $\frac{1}{2}$ hr. in the salt spray. Oxide coatings are primarily used for other purposes than for their protective value against corrosion. The effects on fatigue life of the object by the black oxide coating on it are relatively low; they reduce fatigue life on the order of 5 to 10%.

Oxidized finishes are formed on steel in three general manners. One is in a fused salt bath (niter), which was rather widely used before the war for lighter coatings and blue-black coatings. Another method is heat tinting, which is largely confined to small parts, and the work done in tumbling barrels or retorts. "Browning", the most popular method, which gives the heaviest coatings of all, involves the use of hot alkaline oxidizing solutions. These methods are adequately described in an article in the  *Metals Handbook*, page 1118.

Blackening of copper alloys can now be done, thanks to recent developments, by the formation of cupric oxide coatings which are very adherent and which give good protection to the base metal. The oxide coating can be bright or very dull, where an optical surface is wanted or where beauty is the consideration. The corrosion protection afforded to most copper alloys with uncoiled coatings is of the order of 25 hr. in the salt spray. They are used where heat absorption, reflection or radiation must be controlled on the copper surfaces. They are also used in contrast coloring—for example, in the making of nameplates. The oxide finishes are also excellent paint

bases for copper alloys, particularly brass. Brass is a difficult base to get permanent adhesion of lacquers or synthetic finishes, and the oxide coat has solved the problem.

The coatings also have relatively good heat stability, being made of oxide which is stable and, unlike sulphide finishes, does not decompose.

There are several methods of applying the cupric oxide coatings. One method is to heat the metal with copper nitrate in nitric acid; another method is to use the "copper carbonate ammonia" solution familiar to the plater for so many years. The blue-black coating that this puts on brass and certain copper alloys, however, doesn't protect the copper surface very much, about 2 hr. in the salt spray. There is an electrolytic method of blackening the oxide coating on copper alloys, involving reverse current and caustic soda solution. Lastly, there are chemical oxidizing solutions for producing coatings at boiling water temperatures in 5 to 15 min.

In regard to coloring, which will be more and more important in postwar years, it is possible to produce beautiful effects on copper and brass directly upon buffed surfaces. Blues, antique finishes, old English, and statuary bronze finishes are some well known ones. I think they will be much more widely used than the sulphide finishes, which are difficult to form and which are unstable.

Some chemical treatments have been widely used for aluminum rather than electrolytic anodizing. For example, there are methods of producing a thin oxide coating containing chromate. These coatings are relatively thin, of the order of 0.00005 in., but they are of value when parts can't be racked very readily for electrolytic anodizing, such as rivets and other small parts. They give particularly good protection to alloys that contain no copper, for example, 2S, 3S, and 52S aluminum. Salt spray resistances on the order of 250 hr. or more can be had by a 15-min. treatment in these solutions, usually modified sodium carbonate, sodium chromate or dichromate solutions. Another advantage of the coating is that it is free from perforation, frequently experienced on thin aluminum surfaces after electrolytic anodizing. The corrosion protection afforded is on the order of 20 to 50 hr. in the salt spray.

Chromate Finishes on Zinc, Cadmium and Magnesium

By R. M. Thomas
Vice-President
Rheem Research Products
Baltimore, Md.

MOST of this brief note will be directed to a description of methods of protection of zinc and cadmium finishes, because the status of chemical finishes on magnesium, included in the title, is still in the developmental phase. It has been mentioned earlier in this group of articles that zinc and cadmium are well known as protective coatings for steel, based chiefly upon their sacrificial nature. The prime purpose of a further chemical coating for these two metals is to reduce the tendency of either the zinc or the cadmium coating to undergo corrosion in ordinary atmospheric environment or to discolor or otherwise become unattractive, or otherwise to lose their general utility.

The finishing of metals with a chromate coating is by no means new. A search through the patent and technical literature shows that they have been in use for a great many years. They are applied very economically and rapidly by dipping the work in a properly prepared solution for a length of time varying from 15 sec. to 2 or 3 min., removing, rinsing and subsequently drying.

The advantages of these coatings have been based chiefly on their ability to give corrosion resistance to both zinc and cadmium, either plated or dipped, or zinc die cast products. Some of the characteristics which have been tried and found wanting in such coatings have been their relative softness and thinness, which results in relatively easy abrasion. Corrosion resistance of many of these coatings has depended on a slight solubility, which permits the leaching out of soluble chromium salts, which passivate any bare or exposed metal at a scratch or an abrasion. The net result of this mild degree of solubility of the coating, of course, has been to reduce its over-all life.

Finally, the control of color in the older chromate processes has been acquired fairly slowly. If the material or the work is adequately coated — adequately for corrosion resistance — there has been no great degree of emphasis placed upon a desirable color.

However, there have been processes developed during the past two or three years based on a study of the mechanism of formation of these films and on the nature of the film itself. New methods for producing, first, harder films

and second, more uniformly colored films, have resulted. Finally, films are now made which can be colored to suit decorative needs. Since these films have become available,

I have observed that their original purpose has been greatly enhanced. In other words, the use and utility of zinc plated articles and zinc die castings can be greatly increased by prolonging their life, by prolonging their resistance to corrosion, and by improving their over-all attractiveness by coloring.

The relatively small differences between zinc and cadmium, chemically, mean very little to the chromate finish. The practical differences between the coatings produced on these two metals, I believe, are chiefly technical differences in the plating methods. The two metals behave so similarly in the chromate solutions that one may be substituted for the other without any recognizable difference. Likewise, corrosion resistance and final color are apparently equal for zinc and cadmium.

As far as magnesium is concerned, most metallurgists are familiar with the fact that almost all magnesium products, either sheet, extrusions, sand castings or die castings, are commercially finished at the mill with some form of chromium film. Here again, we have a metal which is useful chiefly on account of its light weight, but which has a very specific problem in its corrodibility. With all due credit to the good work that has been done by magnesium producers to show what alloys or what purity are desirable for this, that or the other exposure, it is very interesting to remember that parts made of this metal are very seldom handled, shipped or stored without all portions being covered with a chromate film.

Here again, I feel that a good deal more study must be made on the type of film which forms on magnesium to even attain the amount of success as measured by the number of hours in the salt spray test, for example, that is attained with zinc. I believe some of these commercial applications on magnesium today probably do not exceed 20 to 30 hr. of life in the salt spray. That, of course, is relatively low as far as corrosion resistance is concerned, and certainly chromate films today on magnesium must be considered as still in the developmental stage. ●

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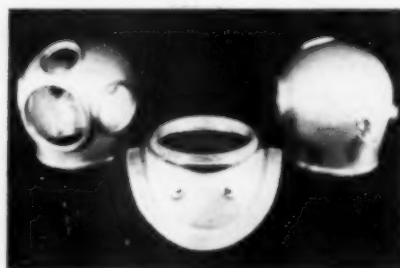
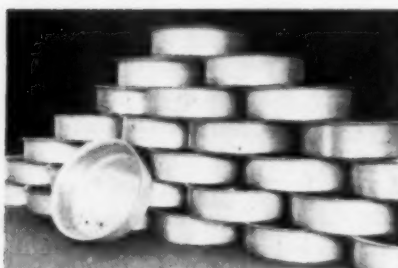
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Powder Copper*

BEFORE THE WAR, all copper powder used in Britain was imported, and there was no considerable local production until the middle of 1943. It was simple for Germany and America to produce powder cheaply in their large copper refineries, as electrolytic copper powder is deposited under similar conditions. British manufacturers have the handicaps of expensive electricity, and small plants which must use refined copper for their raw material. Although other processes such as atomization would be cheaper, the users of copper powder demand electrolytic powder with which their technique was developed.

The leading British manufacturer supplies three main grades of powder: (a) Rather coarse powder of 40 to 100 mesh, with a loading weight of 2.2 to 2.6 g. per cu.cm. (b) Grade M, the most generally used, which corresponds fairly closely to American "B", heavy quality; (c) extra fine grade which is similar to American "C", special grade, but with a higher loading weight. All are made to rigid specifications.

Porous bronze bearings, motor brushes and impregnated diamond tools have been made in Britain for some years. Several firms are now experimenting with other products.

Success or failure in powder metallurgy is said to be largely dependent on the use of the right type of powder. Each of the three principal types of copper powder (electrolytic, gaseous reduced and atomized) has its natural field of application. Atomized powder is easily recognized by the spherical particles. Reduced powder is generally coke-like, while the electrolytic particles are dendritic. Atomized copper is little used in powder metallurgy as the spherical particles are difficult to compress into a coherent form, but it is extensively used in the chemical industry for a reagent, and for the manufacture of welding rods. Reasons for the preference in Britain for electrolytic instead of gaseous reduced powder are not entirely clear.

Powder for metallurgical purposes is generally minus 180 mesh or minus 300 mesh. The latter is more suited for non-porous compounds.

(Continued on page 976)

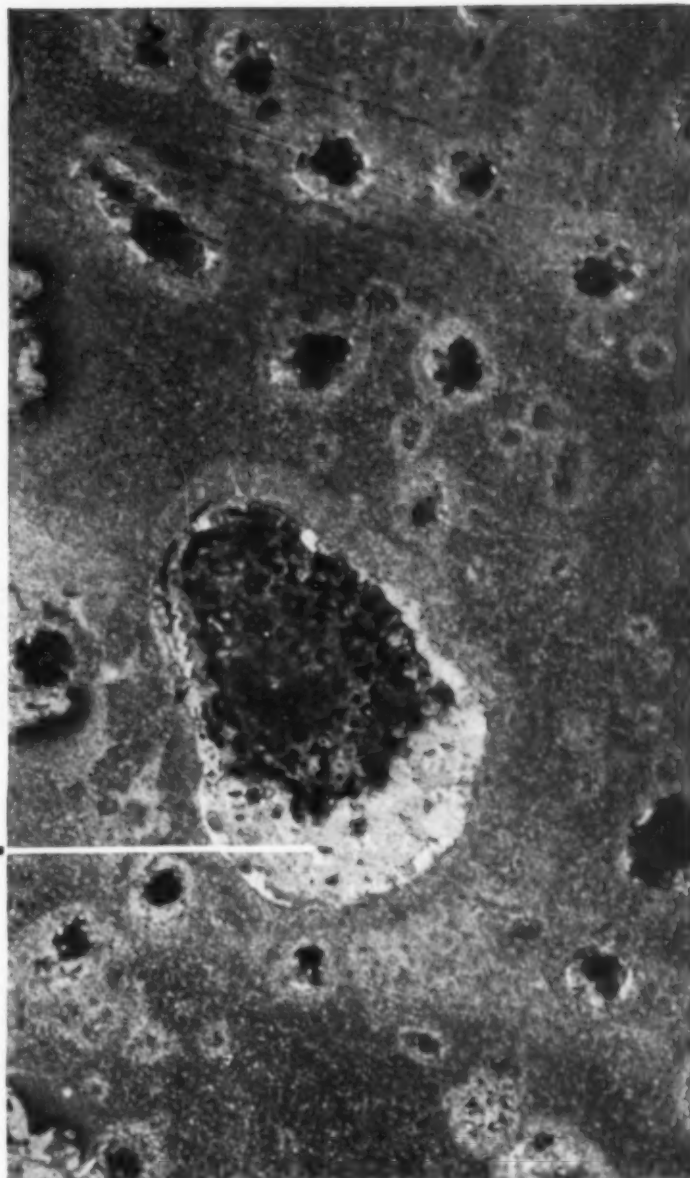
*Abstracted from "British Electrolytic Copper Powder", by H. W. Greenwood, *Metallurgia*, August 1944, p. 181.

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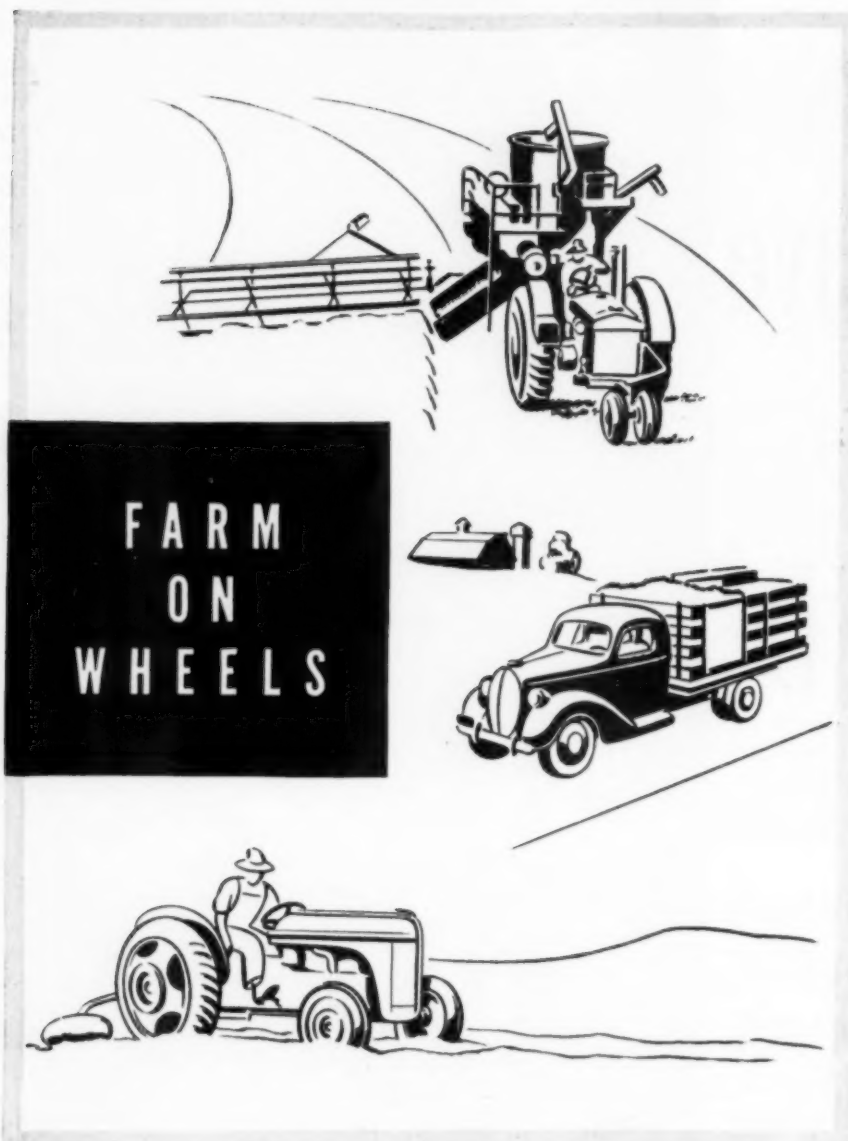
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Powder Copper

(Continued from page 970)

pacts, while the coarser powder is used for porous materials and for hot pressing. For mass production the loading weight must be predetermined and maintained constant. For the manufacture of small articles on mechanical presses, it is generally necessary that the powder be free flowing; especially in this true if magazine feeds are installed on the presses.

Apparently the exact suitability of any powder for its proposed use can be determined, at present, only by complete laboratory tests and ultimately by trial runs.

Chromizing*

RECENTLY considerable attention has been given to the chromizing (the impregnation of the surface with enough chromium to make a corrosion resistant analysis) of iron parts to counteract corrosion. The success of the diffusion of the element chromium into the iron depends on the effective and uniform supply of chromium to the surface being treated and the maintenance of conditions favorable for diffusion to sufficient depth.

Some proper chromizing medium is obviously essential. Solid materials or liquid or gaseous chromium metal have proven unsatisfactory. When gaseous chromium chloride (melting point, 1510° F.) is used, it is possible to deposit chromium on metal in contact therewith.

Russian work which compares a solid medium and a gas treatment showed that the depth of case increased with temperature, even though the depth after the gas treatment was about twice that for treatment in a solid medium. In the latter, the depth increased with time and with the flow rate of hydrogen gas, used for protection against oxidizing or side reactions. Chromium gave a deeper case than ferrochromium. An increase in the carbon content of the steels being chromized in gas tends to decrease the case thickness, as the diffusion of the chromium is hindered by the carbides. (Continued on page 980)

*Abstracted from "Chromizing Processes, a Survey of Latest Russian and German Research", by D. W. Rudolph, *Metallurgia*, June 1945, p. 59.

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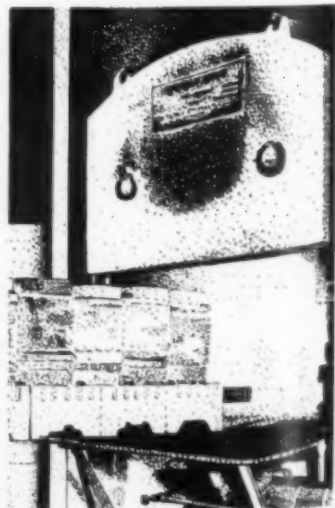
Chromizing

(Continued from page 976)

The Germans have announced new carrier gas (composition not given) which overcomes the difficulty encountered in the gas process due to the relative high density of chromous chloride, for example, which impedes the production of homogeneous mixture within the retort and in contact with the work. Chromized materials had corrosion resistance approximately the same as 18-8 and 17% chromium-iron, but obviously the protective effect of a very shallow chromized layer is only temporary.

The chief disadvantage of the gas process is its restriction to special materials. Steels with 0.5% titanium give satisfactory results with up to 0.13% carbon, while 3% chromium steels or high manganese steels are good for carbon content only up to 0.10%. High titanium contents increase the case depth.

If chromous chloride is mixed with other chlorides, it will remain stable in a bath up to 2200° F. Higher concentrations can be maintained in the bath than are possible in a vapor phase. The case depth varies greatly with the $\text{CrCl}_2:\text{CrCl}_3$ ratio; the optimum proportion depends on the material being chromized. The undesirable effect of higher carbon contents of the material being chromized can be counteracted by the addition of vanadic chloride to the bath; the diffused vanadium impedes the carbon diffusion into the chromized layer but does not affect the chromium diffusion. Therefore, the depth of the chromized layer may be increased seven times by the use of vanadic chloride in the bath.



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Microhardness of Austenite and Martensite*

A NEW microhardness tester is described wherein the diamond penetrator is mounted in the center of the front lens and it was used for the determination of the hardness of martensite, austenite and their transition products in a 1.7% carbon steel. The penetrator is a small four-sided diamond pyramid similar in shape to the Vickers pyramid. A force of 1 to 100 g. can be imposed. The optical system is designed with a high power res-

olution (0.3 to 0.4 micron) so that a hardness measurement can be carried out on areas as small as the wave length of light.

To make full use of this power of resolution of the new objective, it was necessary to grind the pyramid indenter so carefully that optical tests could no longer reveal a deviation from its prescribed form. The pyramid used for the tests was capable of producing an indentation of definitely square shape, the

sides of which measured less than 1 micron.

Slices of the 1.7% carbon steel, cut 8 mm. thick, were quenched from 2050° F. in a 10% saline solution, and tempered at various temperatures up to and including 1200° F. All hardness indentations were measured immediately after being made. Martensite was tested with loads of 5, 10 and 15 g., and austenite with loads of 2.5, 5, 10 and 20 g. In every case the time of loading was 30 sec.

The tests on martensite were carried out on small needles from which sufficiently uniform values could be obtained. The hardness of the broad martensite areas always varied considerably, presumably because these areas were thin flat "crystals" which were completely penetrated by the pyramid.

When tempered over 475° F. the fine gray needles formed in the austenite were so numerous it was impossible to test the remaining austenite. Apparently the final transition of austenite was preceded by a partial recrystallization, presumably the formation of these fine needles of martensite.

The hardness of the martensite was considerably greater than that of the austenite (868 versus 239, quenched). Within the austenite the hardness was uniform both close to and away from the martensite needles. This would support the theory that the formation of martensite takes place without the diffusion of carbon through the austenite. After heating several hours at 200 to 300° F., the hardness of the martensite increased to 1100 while that of the austenite changed only slightly. The transition from tetragonal to cubic martensite was thus attended by a considerable increase in hardness. The slight increase in the hardness of the austenite was presumably due to the continued precipitation of ultra-fine needles of martensite.

Tempering at 480° F. gave a hardness of 750 for both the martensite and austenite. Therefore, above 480° F., the austenite changed into products of the same hardness as the transition products of martensite. Tempering at higher temperatures caused a steady decrease in the hardness of both austenite and martensite.

*Abstract of "The Determination of the Hardness of Martensite and Austenite by Means of the Microhardness Tester", by H. Hanemann, *Metallurgische Archiv für das Eisenhüttenwesen*, Vol. 15, 1942, p. 403).



In the new Globe Tumbling Barrel Catalog, partially illustrated above, you will find the final solution to your finishing problems. It contains complete information about the nine different types of Globe Barrels in their various sizes and capacities. You will find that there is a Globe Tumbling Barrel for almost every type of finishing operation—de-burring, burnishing, polishing, painting, japanning, or drying. All of them are designed to provide finer finishing at less cost. This new catalog plus Globe's Finishing Service Department are waiting to serve you. Write today!

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Instruments for Measuring Dimensions

A General Review

By Orlan W. Boston
Chairman
Dept. of Metal Processing
College of Engineering
University of Michigan

IN 1900, General Knudsen once said, when he first used mechanic's tools in this country of his adoption, a scale reading to $\frac{1}{64}$ th of an inch was used to make the finest measurements. Then during the first World War, and since, the micrometer and vernier reading to $1/1000$ th of an inch came into general use in manufacturing, but only during the war just ended have we commonly made measurements to $1/10,000$ th of an inch, at least outside the laboratory or air-conditioned tool room.

We can pass over the various definitions for inch, yard, and meter with only the note (which illustrates the way mensuration has grown somewhat haphazardly rather than by plan) that the legal inch is about two-millionths of an inch longer than the inch approved by the American Standards Association. This may be thought of as an immaterial difference, but when we are able—as we are now—to measure to 0.0001 in. in the shop, we are approaching the

time when such differences in “standards” must be taken into account. At the present time they are largely the concern of gage manufacturers. As a matter of fact C. E. Johansson was the first to establish a commercial “master inch” (that is, gage blocks) which at constant temperature could be used in various plants to set measuring instruments to the correct value. This, more than any other thing, has facilitated the manufacture of interchangeable parts.

Shop measurements are now divided into two general classes—direct and comparative. A direct measurement determines the actual or absolute size of a linear dimension; this involves the use of measuring instruments. A comparative measurement, on the other hand, is one made to determine whether a given dimension is equal to, greater, or less than, a given amount; this is “gaging”.

As an example of comparative measurements, attention is invited to the American methods of dimensioning parts. Tolerances are set up for each dimension so that limiting values, low and high, of each are given. Whether the part is within these limits can be determined more accurately and quickly by gaging than by measuring. Gaging, therefore, goes hand in hand with the manufacture of interchangeable parts in production.

Measuring, however, furnishes the basic accuracy in the manufacture of gages. Of course, direct measurements may be made with many types of gages, such as gage blocks, and (similarly) many gaging operations may be made with measuring instruments, such as the use of a micrometer caliper as a snap gage. Also, many so-called gages are in reality measuring instruments—for example, the micrometer depth gage.

Measuring instruments and gages for linear dimensions may be classified as follows: (a) Measuring instruments; for example, the scale. (b) The micrometer, such as the caliper, depth gage, length and external gage, and the plug micrometer gage. (c) The vernier, equally divided. (d) Blocks, master blocks. (e) Indicators, beam and dial measuring machines. (f) Comparators, in which we have indicators, mirrors for optical types, electrical and pneumatic. (g) Projectors. (h) Instruments using light

interference, such as the interferometer and optical flats.

Another classification of gages may be made as to their function or form. Thus: Working, inspection or master gages; internal or external gages; fixed or adjustable gages; limit or non-limit gages; shape or form gages; plug gages; ring gages; snap gages and so on; indicating gages; functional gages; microscopes; comparators; projectors.

You will notice that some of these occur in both groups; they may be used as measuring instruments or they may be used as gages for comparative measurements.

Measuring, even to 0.001 in. implies *accuracy*. The micrometer, vernier or other measuring instrument should be set to known standards;

temperature and operating pressure must be kept close to normal values. As *precision* measurements are made, even to measure accurately to 0.0001 in., more and more care must be taken with temperature control, but the instruments must then be designed to relieve the operator of some responsibility by providing constant known pressures or specific magnifications.

As the accuracy of measurements increases, more and more skill is required of the operator. A good operator can do more with poor equipment than a poor operator with good. The successful use of optical flats, for example, depends almost entirely upon the skill and care of the operator; for this reason, optical flats are not being used to their full advantage as devices to measure to a few millionths of an inch.

Rules, Micrometers and Calipers

WHEN WE THINK of quality control, as applied to the linear measurements of parts, we think of all the measuring tools indiscriminately that are used by industry today. We also more or less group them according to the degree of precision or accuracy required.

This reminds me of an incident which happened about 30 years ago. A newly hired "machinist" was being interviewed by the general foreman (Charlie Poole) of the production machine shop of the old Remy Electric Co. at Anderson, Ind. He was asked to display the tools that he had brought in. The first exhibit was a 6-lb. wagonmaker's hammer, which he was told to take home. The next was a set of 24-in. calipers, which he was also told would be of no use on his new job. The third item was a 2-ft. folding rule. Old Charlie wanted to know what that was and the new hire was getting rather exasperated by this time and he rather vehemently said, "That is my rule that I measure things with." Old Charlie, in contempt, said, "You might as well take it home too, because we have a cornfield right next to the plant here, and them cornstalks grow exactly 6 in. between the joints, and we all use them to measure with around here."

In more recent days there have evolved five principal factors to govern the selection of instruments to control any given dimensional requirement of a part.

1. The degree of accuracy required (part tolerance).

2. The dependability of the instrument (its accuracy).

3. The human equation (errors in use).

4. The rate of production required (type and cost).

5. The availability of the instrument (delivery).

There may be other pertinent factors in special instances, such as those that involve the possible mutilation of a highly finished part by the measuring instrument.

We in industry are deeply indebted to the International Business Machines Corp. and the New York University for the compilation and publication of a monograph on "Precision Measurement in the Metal Working Industry". Every person who is interested in linear measurements should add this book to his working library of technical information. I intend to quote freely from its text.

The rule and the caliper are classified as non-precision line-graduated measuring instruments. "The term 'line-graduated' is here applied to the simpler and more common types of instruments such as rules, calipers, surface gages, and depth gages, where the accuracy of the measurement is largely dependent on the user's ability to

By H. D. Hiatt

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line-up and read the graduations on a scale. Non-precision, line-graduated measuring instruments of this type are used where accuracy in terms of thousandths of an inch is *not* required.

"Some older mechanics will scoff at any suggestion that they cannot read to two or three thousandths on a scale graduated in 64ths or hundredths, and they can prove it. There are a great many skilled mechanics and tool makers who have worked around tools and instruments so long that their eyes are practically graduated in thousandths. But still it is an 'estimate' when anyone attempts to read a scale graduated in 64ths in any unit less than 64ths. Besides, it is not necessary, because there are now available many instruments capable of reading accurately in thousandths. In general, where an instrument is used in the shop to control the accuracy of a dimension on a part it should never be necessary to read *part* of a scale division. In some types of laboratory or special work it is desirable to get as close as possible to the exact dimension, in which case it is common practice to estimate fractional parts of a division."

We believe that everyone in the metal working industry subscribes to and practices the foregoing rules.

The micrometer and vernier calipers are precision instruments within certain limitations. The micrometer is more accurate than the vernier. A good micrometer will be accurate within 0.0002 in. in the range of its spindle travel, while a vernier should be accurate within 0.001 in. in any one inch of its length. In any 12 in. it should be accurate to within 0.002 in. and decrease in accuracy about 0.001 in. for each additional 12 in. thereafter.

The general policy, adopted throughout industry, is to allow the inaccuracy of the measuring instrument to be 10% of the tolerance allowed on the part being measured. The inherent error in micrometers and verniers, together with the "human equation" of user's ability, therefore precludes their use for measurement of tolerances that are up to ten times the inherent error of the instrument.

The "super-micrometer" is used extensively in maintaining the dimensional quality of thread gages and spline plug gages. With it we use the three-wire and two-pin measuring method. The human equation for error is greatly reduced because the measuring pressures are maintained uniformly; there is only one change from a 1-lb. pressure for measuring 20-pitch and finer threads to a 2½-lb. pressure for the coarser threads and for measuring dimensions of spline gages over two pins.



We should mention the indicator type of calipers which are used extensively in the inspection of castings and forgings. Many special shapes of jaws or anvils are made to reach into inner chambers that are partly concealed. Although the inspection of castings and forgings is not considered precision measurement, the use of the indicator calipers (which approaches a precision instrument) is very desirable because it reveals accurately and at a glance the amount of variation that a part may be out of tolerance. This variation is recorded on the rejection tag for the benefit of the salvage committee to determine whether to accept or scrap.

I recently saw an ingenious steel tape-measure in a plant making exhaust manifolds for aircraft engines. This tape was used for measuring the circumference of welded tubular shaped parts, which are somewhat out of round at the time, but would later be rounded up on a plug or horn. The tape had a transverse kink or offset in it at the zero end to permit its edges to butt against each other when wrapped around the pipe in a true plane. At the zero point there were vernier graduations, which enabled the operator to read the tape to 0.010 in., which really meant that she was checking diameters within approximately 0.003 in.

In conclusion, I would like to reiterate that rules, micrometers and calipers are not tools for precision measurement in our mass production industries of today. They do, however, remain on our list of equipment for quality control, and will always be used for work within their several limitations.

Comparators

By W. H. Baker

Chief Inspector

Aircraft Engine Division

Packard Motor Car Co., Detroit

WHEN occasion arises, as it does today, for us to review the industrial accomplishments of this truly gigantic war operation and to forecast some of its effects upon the future, we must think back over a long chain of development—developments that have been at times both slow and hard—developments that date not from Pearl Harbor but from the turn of the century.

For 28 years I have worked on the problems of precision manufacturing and control with Packard Motor Car Co., both as an inspector and as an engineer. And I have come to one firm

conviction: That there is no new era, no marvelous new method, not even any truly new idea that will "revolutionize" industry overnight.

Much has been said about the advantages of fixed limit gages, and much that has been said may apply truly—I do not know—to scattered operations of a lower degree of precision than the manufacture of aircraft engines. One great difficulty with fixed limit gages, in my experience, is that they require too much attention in periodic checking for wear. The preference for comparator gages has been reinforced by experience at Packard's engine division—one of the toughest jobs of engine building that was ever undertaken by any manufacturer—where some 1850 men and 2900 women were on the regular roll of the inspection department. Their job was to see that control was maintained over quality of a design that required more than 77,000 gaging operations per engine, that used more than 200,000 gages, that employed more than 300 people to make periodic inspection of gages alone, verifying some 5000 gages each day. This whole

aircraft engine operation has been one of the largest laboratories for testing the use of different kinds of gages in the history of industry.

So once more I am forced to rely on several decades of experience, in predicting that comparator gages must supersede fixed limit gages, if we are to continue toward better and more economical manufacturing. Their accuracy, their speed, their economy in relieving the highly trained inspection personnel—all force that conclusion.

Early in Packard's aircraft program, we realized that we were going to have to take housewives and teach them how to check thousands of dimensions to tolerances of ten-thou-

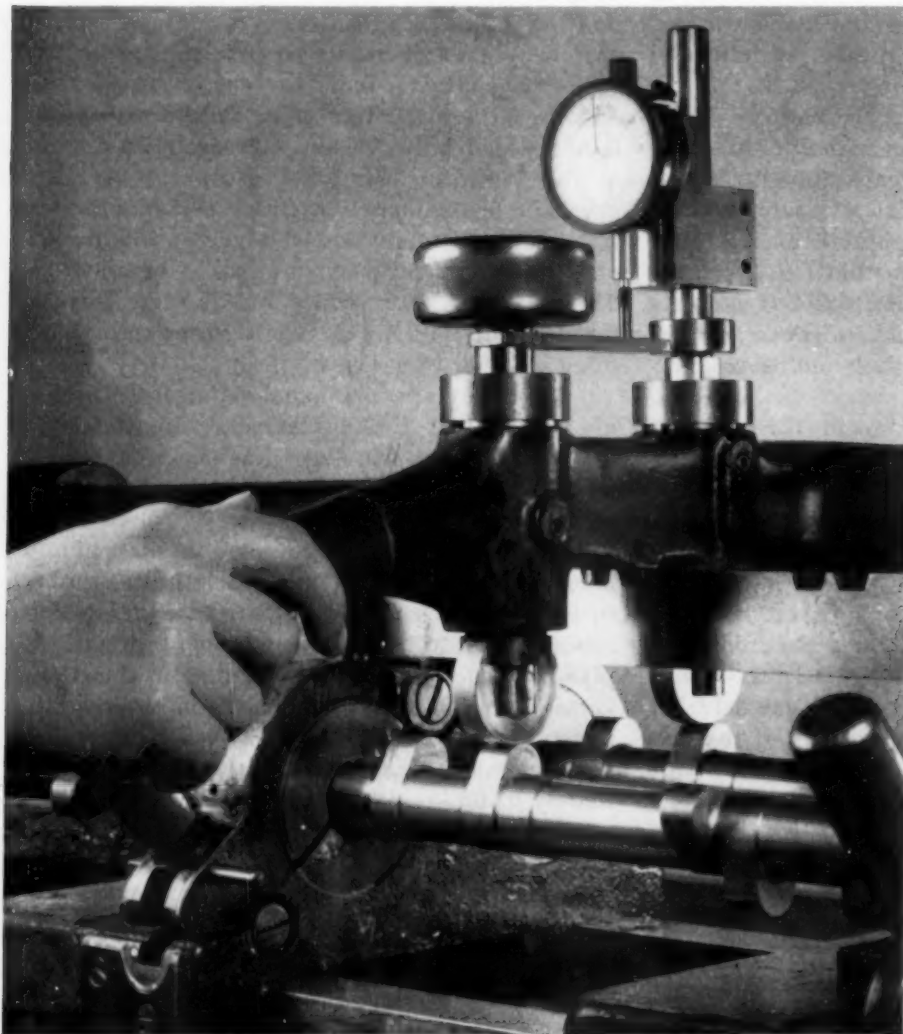


Fig. 1—Close-Up of Gaging Rolls and Dial Head for Comparing Lobes on Camshaft to Master Shaft in Rear

sandths of an inch; that shoe clerks, clergymen, stenographers, manicurists, school teachers, would have to fit quickly into a pattern of inspection that measured in millionths of an inch.

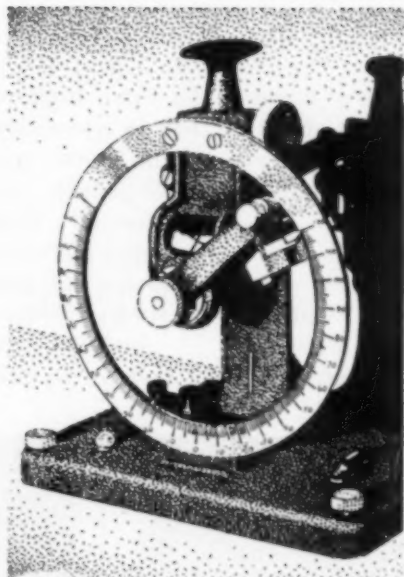
Bearing in mind the type of labor which would be available to do the job, we planned on the maximum use of comparator gages. From experience and knowledge available in the old car division we drew uses for comparators for every close job that we could.

For example, a comparator for the cam lobes on Packard automobile engines was designed by the writer more than 15 years ago. The same style of comparator made 100% inspection of aircraft engine camshafts. Photographs taken in the shop of these gages in the 1920's and 1940's show little change other than the style of the operator's hair-do and her working clothes. One young woman checks all lobes on 120 shafts a day. It would require 36 girls using dividing heads to do the same job. The principle of the device is shown in Fig. 1. The gaging rolls in this close-up ride the lobe being checked in front and the master lobe in back. The notched bar between gaging rolls locates the gage to check any desired lobe. This comparator is motor driven, and it is not necessary to stop the motor to go from one lobe to another.

We have long used Federal roll checkers for pitch diameter of threads. Recently, my associate, George Peets, and I developed a split roll for this type of indicator, shown in Fig. 2. This close-up shows the divided lower rolls on the improved equipment. It gives a floating alignment and assures practically the same accuracy as a three-wire comparator, and it has much greater speed.

Electrolimit gages, which are widely used throughout industry, are equally widely used by us at Packard on such jobs as gaging the piston pin hole, outside diameter of pistons. The battery of bench gages shown in Fig. 3 operates in the connecting rod department. This type of equipment is rugged enough so it can be mounted temporarily on conveyer tables alongside production, and check current parts to quickly ferret out sources of off-gage parts.

In checking small parts to close limits, the comparator is outstanding. In our aircraft engine divisions, more than a million pieces a day go



through receiving inspection; on many of them an accurate check, with the type of labor referred to, would be impossible except by the indicating comparator.

Sheffield's visual gages are used both on production and for special precision checks at inspection stations. In our gage rooms, which check 5000 fixed limit gages a day, and in our cold room where masters are checked, the visual gage is also widely used. Even at production machines, these gages have been found very useful to prevent time and material losses.

We also use many hand snap gages equipped with tungsten carbide rod insert in upper and lower anvils. A typical use is to check the pitch diameter of splines.

Finally, hand comparators and indicating calipers are widely used for checks on wall thicknesses and casting dimensions. We section about 1% of castings to make sure that oil lines and other details have no concealed defects.

I regret that it is impossible to go into more

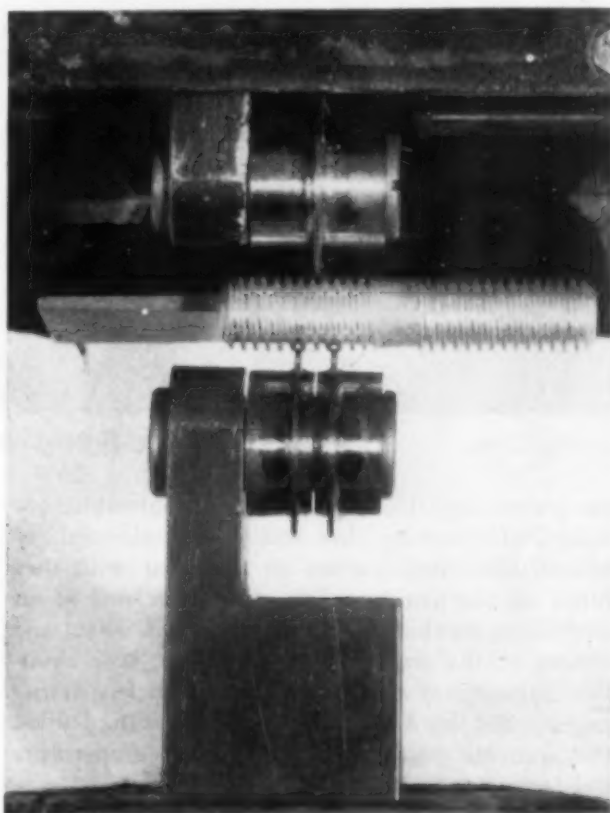


Fig. 2 — Divided Lower Roll on Gage for Checking Pitch Diameter of Threads

complete detail on the thousands of uses of comparators; I can only say that virtually any check which is worth making can be made more quickly, more accurately, and with absolute uniformity with such equipment.

Incidentally, such inspection requires a great deal of coordination. Any gage trouble, of any magnitude, finds its way quickly to Central Inspection where the best layout and trouble men in our organization, with every type of measuring

the same high ratio of inspection-to-production that is necessary for wartime matériel. That means more rapid and more accurate gaging by fewer people. Comparators provide this.

Second: Complicated systems for periodical checking of fixed limit gages will not be practical in motor car production. Comparators require no such systems.

Such conclusions are not reached on a basis of opinion or guess. We have inspected at least



Fig. 3 — Battery of Bench Gages in Connecting Rod Department

equipment, get the answers to the trouble, get them right and quickly. It is not claimed, of course, that comparators do not wear with use. Wear on the gaging point, spindle or roll of an electric or mechanical comparator can affect the setting of the gage. That's why we had about 300 inspectors doing nothing but inspecting gages. But by their help we always had good and accurate gages in the hands of our operators and inspectors.

Summary — Looking over the entire situation, I might summarize some of my thoughts.

First: Peacetime operation cannot maintain

five million gages for wear. We have inspected literally billions of parts and tens of billions of dimensions, with every type of equipment known. (Incidentally, the daily service and engine production requirement at peak production required more than 6,000,000 measurements.)

It is my considered opinion, therefore, that the gage of the future is the gage which can be applied to many uses with a small cost for new masters, which will last almost indefinitely, and which gives the same answer at any time with any operator, and which conserves man-hours.

That gage appears to be the comparator. e

Instruments to Establish Identity

Magnetic Comparators

By J. J. Smith
General Engineering Laboratory
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ACCELERATED production under wartime conditions, with its accompanying problems with the materials used, has stimulated the development of numerous non-destructive tests for quality control of materials and parts. One of the earliest and most important problems showing up in any production line is the verification of the identity of each piece of raw material. How can one be sure there is not a tramp bar in the shipment. It has the same size and shape and the same color. It may cause trouble in machining, yet if its machinability is similar to the rest of the lot, it might readily escape a careless or sleepy operator. It would then fail to respond to heat treatment, but if the plant is operating under less than 100% inspection, a dozen or more pieces could get clear through and be incorporated into final components to the danger of their correct functioning.

How can such mix-ups be discovered?

The magnetic comparator, as the name indicates, compares the magnetic properties of the raw or finished materials under test with those

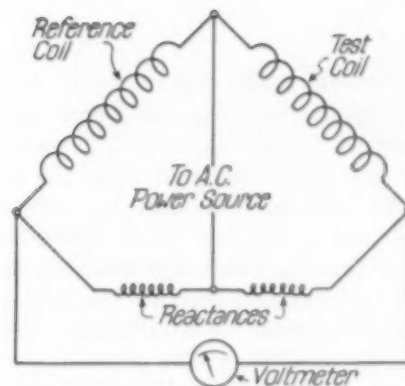


Fig. 1—Fundamental Circuit
for Magnetic Comparators

of a known specimen, and it has been successfully used to separate the good from the bad with a consequent saving of time and money.

First it will be desirable to have a general idea of how these comparators work. When magnetic materials are being studied for use in electrical machinery, laboratory measurements are made of the magnetizing current and core loss for various values of the magnetic induction in the materials. For each metal typical curves can be drawn showing the relation of magnetizing current to flux density. The shape of these curves is quite characteristic for a given material, although for any given material it may vary considerably depending upon the heat treatment or mechanical work received. Information given by these curves could obviously be used to compare different magnetic materials. For example the maximum "intrinsic flux density" for monel metal is 2000, for commercial nickel is 5500, for high silicon steel is 18,000; and for Armco iron is 21,500. Likewise the magnetizing force required to induce a given flux density of, say, 10,000, varies with the material; for example, 0.08 oersted for electrolytic iron, 2 for silicon steel, 4 for cold drawn mild steel, 10 for low carbon steel casting, 150 for gray cast iron.

A simpler way to proceed is, however, to take two such materials and make the comparison directly by means of an electrical bridge circuit as illustrated in Fig. 1. Two like coils form the two upper arms of the bridge circuit. One of these coils is used as a reference coil and the other is the test coil in which the pieces to be tested are inserted. The two lower arms contain reactances. A voltage is applied at opposite corners of this bridge and a sensitive voltmeter is connected across the other pair of opposite corners. If the materials placed in the reference and test coils are identical, then it is obvious that

the voltage across the instrument is zero because it is connected to points which should be at the same potential. However, if material placed in the test coil is different from the material placed in the reference coil, then the voltage-drop in this arm will be different from the voltage-drop in the other arm, and this will show on the instrument. Thus we can tell whether the two pieces of material are similar or dissimilar.

We may vary this procedure by substituting on one arm of the bridge a variable resistor and inductor for the material. The dials on this arm of the bridge can then be turned so as to obtain a balance on a reference piece. Having set this

square name plate. The large dial to the left of the instrument adjusts the voltage from zero to 130 volts; this is useful, for sometimes the comparison may be made better at one voltage than at another. This instrument is ordinarily used at 110 volts, 60 cycles, and can be plugged into the available power outlets.

A variation of this comparator uses high frequencies, and the set therefore contains an oscillator for generating the special current. At around 2000 cycles, say, it is possible to compare not only magnetic materials but also non-magnetic materials. The latter cannot be readily tested at 60 cycles but by using the higher fre-

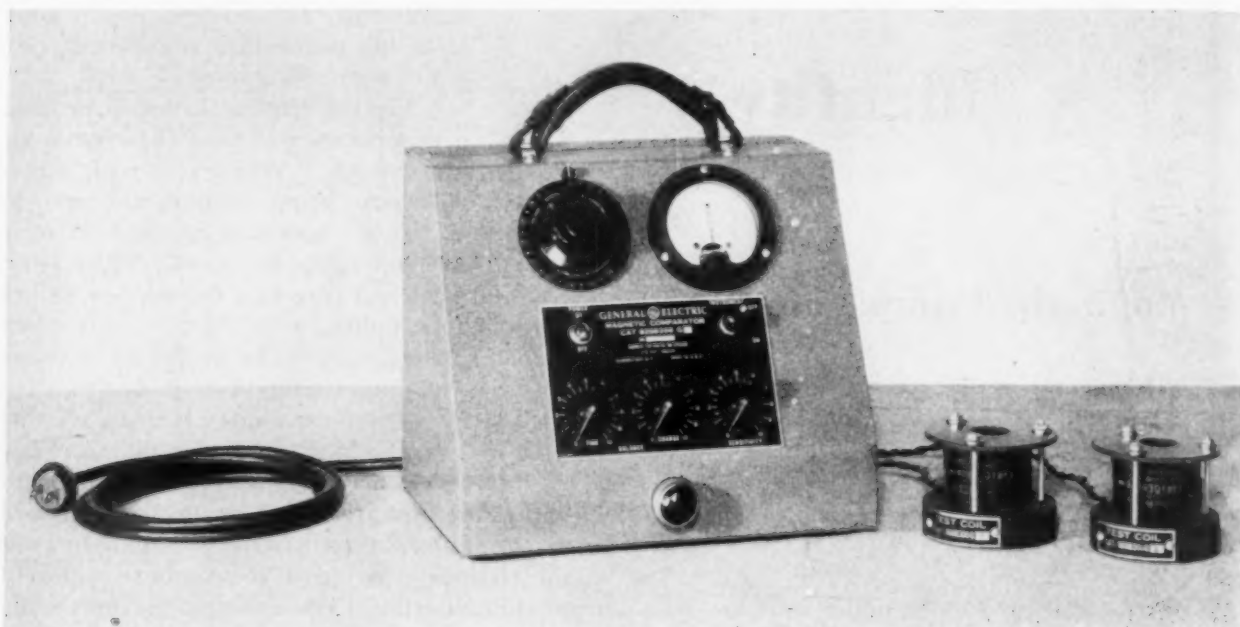


Fig. 2 — Magnetic Comparator for Testing Metallic Items That Respond to Low Voltages and Frequencies

balance we can then use the comparator for control purposes by comparing successive pieces of material. The instrument used to measure the unbalance can be a millivoltmeter on which the reading is made directly. Sometimes a cathode ray oscillograph is used.

This very briefly gives a description of the fundamental ideas which are used in the various forms of comparators for non-destructive testing in quality control. Some of the instruments will now be briefly reviewed.

A magnetic comparator made by the General Electric Co. is shown in Fig. 2. Note the two test coils at the right, connected to the unit in the case which contains the bridge circuit. The indications are read on the panel instrument which normally is balanced to the center point of the scale by means of two balancing potentiometers whose dials are at lower left of the

quency, successful comparisons and distinctions can often be made.

In the variation of the a.c. bridge method illustrated in Fig. 3 only one coil is used. The dials on the unit can be set to balance against known resistors and inductors. The balance is read on a small cathode-ray oscillograph which is the white circle at the top of the box. We use this in the General Electric Co. for checking both stock and parts, especially of magnetic and electrical alloys. In general, the use of two coils is preferable when only a comparison is to be made, but when it is desired to know whether the resistance and permeability of the specimens is too high or too low, more information may be obtained by balancing it against known resistances and inductances.

There are several other instruments of this type on the market. Among them are the Cyclo-

graph and the Ferrograph made by the Allen B. DuMont Laboratories, Inc. Another instrument is the Waugh Induflux developed by the Laboratory Division of Waugh Equipment Co.

The Cyclograph makes use of multiple frequencies to test ferrous and non-ferrous parts according to their metallurgical properties. It is described at length in the following article by Mr. Cavanagh. The Ferrograph employs a low frequency exciting current for simple comparisons of ferrous materials as to their analysis and heat treatment. Both of these instruments use cathode-ray tubes as an indicator to show variations in the characteristics of the material.

The Waugh Induflux is a 60-cycle induction equipment for analyzing the magnetic properties of steel specimens as based on their reaction to alternating current magnetization. Variation in the physical properties causes the induced voltage to vary in amplitude, phase and harmonic content, and it is these changes in the induced voltage which are read directly on an instrument scale which may be calibrated in terms of physical characteristics if desired.

Sometimes one needs to check the hysteresis component. Equipment for this purpose, called the Cathode-Ray Hysteresigraph, has been used. It consists of a magnetizing unit and a cathode-ray oscillograph. It operates from a 110-volt, 60-cycle power supply. The magnetizing unit is made up of a laminated iron yoke, a magnetizing coil, and an exploring winding. These are connected to horizontal and vertical axes of the oscillograph and trace the hysteresis loop on the screen when the test specimen is inserted in the coil system. Limits are established by marking on the oscillograph screen the loop due to standard reference specimens and noting how much the hysteresis loop due to the piece being tested departs from this.

Direct Current Equipment

An important test for much material going into electrical machinery is to determine the magnetic residual after magnetizing. Equipment for this test consists essentially of an electromagnet, a test coil and a flux-meter. The test procedure is first to magnetize the part to saturation, then insert it in a suitable test coil and note the deflection on the flux-meter when the part is withdrawn from the coil, which is a measure

of the residual induction. If the deflection is within predetermined limits, it is acceptable; if not, it is rejected. Reference samples of acceptable parts are used for establishing the limits. Where the magnetic residual is of prime importance to the operation of the apparatus in which the parts are to be assembled, such a d.c. residual tester is more direct in testing such parts. For machinery where the combined magnetic characteristics and resistivity are important, the a.c. comparator is preferred.

Carbon-Meter — Another direct current measuring device of interest to steelmakers is

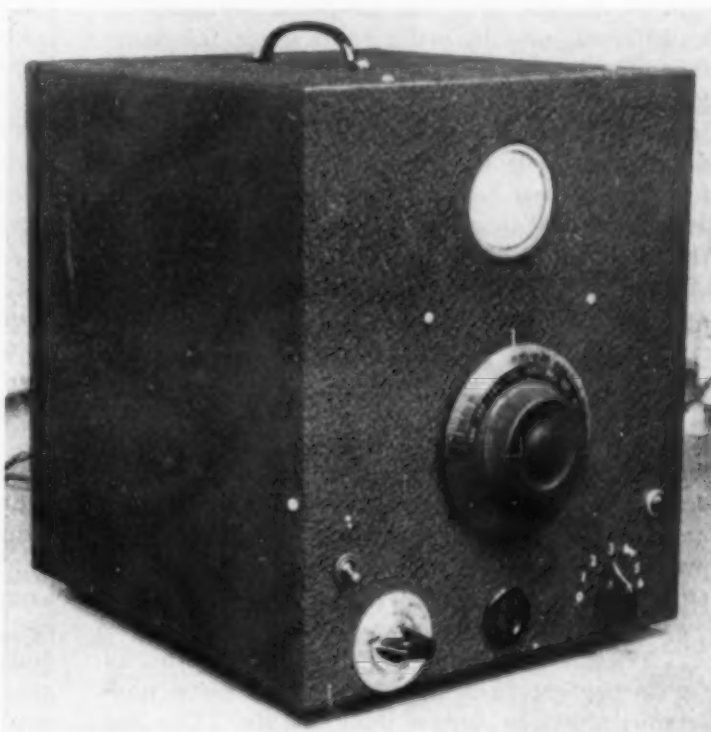


Fig. 3—Instrument Using Only One Test Coil and Showing Results on Small Oscillograph Screen (Top Center)

known as the Carbon-Meter and is manufactured by E. Leitz, Inc. of New York City. It has been designed for rapidly determining the carbon content, at the furnace, of samples cast from molten steel during the process of steel refining, when speed and accuracy are very desirable. The instrument has two ranges. The range for unhardened steel is from 0.04 to 0.40% carbon and for hardened steels from 0.30 to 1.25% C.

The method of operation consists of adjusting the instrument so that the magnetic flux created in the unknown specimen is equal to that created in a standard sample permanently located in the instrument. Both the standard and unknown specimens are surrounded by

primary magnetizing coils. The current in these coils may be adjusted by means of a slide wire, raising the magnetizing field in one coil while lowering it in the other, and vice versa. Identical secondary coils surround the primary coils and are connected in series so that the induced voltages in the two coils are opposed.

When the magnetic flux in the standard is equal to that in the unknown, the galvanometer (upper left hand corner) in series with the secondary coils will not deflect when the current in the primary magnetizing coils is opened or closed by a press button switch. However, when the carbon content of the unknown differs from that of the standard, the magnetic permeability is different, and in order to produce the same magnetic flux in the two specimens it is necessary to increase the magnetizing force around the specimen with the lowest permeability. This is done by adjusting the slide-wire control. The reading is then taken from the slide-wire dial and is referred to a calibration curve from which the carbon content is read for the particular type of steel used.

Conclusion

A brief description has been given of several types of magnetic comparators. Both a.c. and d.c. instruments are available. In general the d.c. instruments are more suitable when the magnetic residual of the piece to be tested is the property desired. Where the combined magnetic characteristics and resistivity are important, the a.c. method is usually more suitable.

These equipments have proved very useful for inspecting ferrous alloys and some non-ferrous alloys to control their quality. This has become more and more essential because of the great demand for uniformity in manufactured products. The tests are non-destructive in nature and are adaptable to either 100% inspection or the sampling technique based upon quality control methods. The equipments are simple to use and the tests can be made rapidly, which is quite desirable when they are used in production.

References

"Magnetic Testing to Control Quality of Ferrous Alloy Parts", by W. K. Kehoe, *General Electric Review*, April 1944.

"Rapid Non-Destructive Material Testing with C-R Oscillograph", by W. A. Knoop, Jr.,

Instruments Magazine, Jan. 1943, v. 16.

"A New Method of Sorting Steels", by R. J. Brown and J. Bridle, *The Engineer*, Dec. 3, 1943, p. 442.

"Non-Destructive Testing in the United States of America", by H. H. Lester, R. L. Sanford and N. L. Mochel, *A.S.T.M. Bulletin*, December 1938.

"A Rapid Method for Deter-

mining Carbon in Plain Carbon Steels for Control Purposes", by H. H. Blossjo, *American Foundrymen's Association Transactions*, 1939, p. 469.

"Magnetic Determination of Carbon in Steel", *The Engineer*, July 19, 1940.

"Correlation Between Hardness and the Magnetic Properties of Solid Matter", by S. K. Williams, *Instruments*, July 1940, v. 13.

High Frequency Devices

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A GREAT DEAL of development and experimentation has been carried out in the last few years to determine the suitability of magnetic testing instruments for practical production inspection. Most applications have been for salvaging satisfactory pieces from mixed lots of parts. A more suitable way of using these instruments is, of course, to prevent such mistakes being made by 100% inspection of parts during production.

"Magnetic testing" of metallic parts that are not intended to act as magnets, but on the assumption that the magnetic properties change when other physical properties change and the two can be correlated, is of course not a new thing. However, most of the earlier flaw detection was accomplished by establishing a uniform magnetic or electrical field in or around a piece of metal. Any discontinuity or crack produces a disturbance in the field which may be detected in a multitude of ways. In this field, the widest known equipment is the Sperry rail inspection car. Sperry Products' units for inspecting tubing and bar stock embody many new features and give a reliable fast test for flaws in ferrous and non-ferrous metals. Tubing manufacturers in the steel industry have also developed their own equipment somewhat similar to Sperry's with comparable performance.

Magnetic Analysis Corp.'s flaw detection device is intended primarily for use on bar and rod stock, and is especially recommended when the stock has been cold drawn or otherwise hardened.

These methods have inherent limitations in that the orientation of a crack has a decided effect on the indication which will be obtained from it and therefore on the ease with which it can be detected. If a crack cuts across a field at right angles it will be much more easily detected than a crack of the same size which lies parallel to the field. There is a minimum size and depth of crack which can be detected.

To remove some of these limitations, equipments which may roughly be termed "magnetic high frequency devices" have been devised, utilizing the new electronic circuits and special cathode-ray tubes, and it will be my effort to describe one embodiment that I have done a good deal of work with.

In order to adopt these new instruments as reliable production controls, it is very necessary that we first know exactly what *not* to expect from them. For successful magnetic testing it might be said that a new metallurgical outlook is needed. It is unfortunately true that many insignificant variables, which do not affect the service life of metal at all, *do* affect the results obtained with these instruments. A metallurgist must take all these facts into account. The problem has been to develop instruments which will respond to desired differences in physical properties without undue effect from unimportant variables. Such an inspection device must reject all undesirable pieces, but also must reject as few as possible of the good pieces because of minor variations in chemical analysis, internal stresses, or surface condition.

Suppose we assume that it has been established that a certain type of experimental instrument will give indications that satisfactorily correlate with some desired physical property. If we are to use this instrument in production and rely on it to reject any undesirable pieces and accept only parts that are within specifications, there are a few simple conditions the instrument must meet. It must be very rugged and simple to operate. The fewer controls the better. It must give reliable, reproducible results. It must be able to inspect parts fast enough to keep pace with production. Finally (since very seldom will one single measurement give sufficient information for production inspection) the instrument should be capable of taking several readings correlated with various physical properties.

There are two basic methods of determining magnetic losses due to changes in physical properties at higher frequencies. The first and earlier one might be called the "transformer principle". As diagrammed in the preceding article by Mr. Smith, energy is put into the metal sample from

a primary coil and the output of the secondary is influenced by the magnetic, and hence the physical characteristics of the metal sample. This method has some limitations, especially at higher frequencies, since it is difficult to construct suitable coils for a wide range of frequencies and to provide a field of sufficient power.

Advantages of Oscillators

The second principle utilizes some type of oscillator whose operation is controlled by the characteristics of the coil in which the metal sample is placed. This type of instrument has several advantages for rough inspection. In the first place, minor surface flaws do not affect the field unduly and differences in size of less than 10% do not cause any trouble. The results obtained at frequencies from about 100 cycles to 2000 cycles are about the same. In order to encompass the most useful range of frequencies on such an instrument, it is desirable to make the available frequency range from about 2000 cycles up to 150,000 cycles. For practical inspection it must be extremely easy to change the frequency on such an inspection device, but provision should be made so that it is difficult to use the wrong frequency. The "Cyclograph", as used for routine inspection, is housed in a cabinet about 4 ft. high, 3 ft. wide and 2 ft. deep. It weighs about 350 lb., and consumes about 250 watts of ordinary 60-cycle, 110-volt current. Figure 1, on the next page, shows the instrument in use—a rather interesting use, by the way.

In practical use it has been established that indications derived from a field of 2000 cycles and higher will correlate with properties of the interior of large metal pieces. This seems very strange to anyone familiar with the skin effect of induction heating at high frequencies. For normal purposes the amount of flux $\frac{1}{4}$ in. below the surface of a 1-in. bar at 10,000 cycles is negligible, but with an extremely sensitive oscillator (of the type used in the Cyclograph) the differences in flux in this outer zone are sufficient to indicate differences in physical properties—*provided* the properties of the surface layers of the bars are reasonably uniform. The practical answer as to whether a certain frequency will give results that correlate with the properties in the *center* of any particular sized piece is to test the pieces in question. If useful indications are obtained, the depth of flux penetration is of academic interest.

To get down to practical applications, it is possible to use high frequency tests of this type to separate metals according to differences in chemical analysis, if the difference in analysis

gives a significant change in structure or physical properties. Since these tests are comparisons only, the function of the instrument is to pick out all pieces reasonably alike in analysis and reject all those which are not sufficiently close to the specified standard. In general, it might be said that different grades of steel can be easily

particular frequency. The chance of this tramp giving the same readings at all three frequencies is extremely remote.

Similarly, in sorting a lot of steel, which is believed to be all of the same analysis but varying as to heat treatment, it may happen that a piece of some other steel, given no heat treatment, may produce the same energy losses at one frequency as the desired steel which has received heat treatment. This erratic piece could not be detected by a single magnetic reading but is identified by testing at more than one frequency.

Since differences in microstructure, macrostructure or heat treatment history can also be detected, it is possible to select from a production lot all those parts which are alike in analysis and structure. Sometimes this will mean that these parts will lie within a specified hardness range, but this is not always true. For one thing, in order to determine whether there is any correlation between hardness and the reading obtained on the instrument, we must use Rock-



Fig. 1 — Checking Contents of Packaged Welding Rods. If any mix-up is made, the curve on the cathode-ray screen assumes a strange shape

distinguished, but magnetic instruments are not recommended for separating heats of the same grade. Small differences in alloying elements in steel will, of course, be most easily detected in the stage of heat treatment where they make the most difference in hardness. Correlation with eddy current losses at higher frequencies also makes it as easy to distinguish between analyses of non-ferrous materials.

To be specific, in sorting S.A.E. 1020 bolts from S.A.E. 1065 and 4130—a mixed lot of several million—automatic feeding devices were arranged and each bolt passed through three coils, one energized by 2000-cycle current, the next by 12,000 and the last by 31,000-cycle current. Go and no-go limits on the scale of each instrument were set for the 1020 steel bolt. It may happen that one particular bolt might be made from 1065, 4130 or even some other steel, and give the same reading as 1020 at any one

well or Brinell tests. If the structure is not uniform throughout the piece—a casehardened piece, for example—no correlation will be obtained because the magnetic instrument gives an integrated value for hardness throughout the section. If heat treatment control is good, structures uniform, distribution and depth uniform, excellent correlation can be obtained with surface hardness. Some materials lend themselves much better to this type of test than others; a difference of 10 points Rockwell in one type of steel may give several times the indication that the same difference in hardness in another steel will give.

One useful type of test that may be performed with high frequency currents is the inspection of surface layers of metals. The comparison of case depths is about the most difficult of these tests because of the large number of possible variables present. If a frequency is

chosen which limits flux penetration to approximately the zone occupied by the case, a very sensitive determination of case depth is obtained—but only if all other factors are reasonably constant.

Since this is never true in production, we use the Cyclograph first at other frequencies to select groups of the parts in which all properties but case depth are reasonably alike. It can be readily seen that if the uniformity of original material, heat treating, and casehardening control is not very good, this preliminary testing would become much too complicated to make magnetic testing practical. While it is theoretically true that if sufficient measurements were taken at a sufficient number of frequencies, any number of variables could be evaluated, no one is very interested in performing such tedious inspection in a plant. In general, if more than three tests at three frequencies are necessary, the test cannot be called "practical".

Practical applications of this type of test have been most successful where the uniformity of the materials and the processing is on a better-than-average level.

Application

Some of the more recent and interesting applications of the Cyclograph might be mentioned.

Internal stresses have a very profound effect on core losses in the test coil. Quenching stresses set up during heat treatment can therefore be evaluated. It is possible to predict which parts have such high internal stresses that they will crack spontaneously after a period of time. Internal cracks that never reach the surface reduce "toughness" greatly. Of course when the piece cracks, even if locally and microscopically, some of the stress is relieved. The more the cracking, the lower the remaining stresses. It is possible to sort pieces such as extruded bolts which have developed "cup fractures" due to high stresses. While most of the dangerous bolts will be rejected because of high residual stresses, some will be found with extremely bad fractures that have been passed otherwise as good bolts, since the level of remaining stresses is the same as for a sound bolt.

Correlation with stresses and the possibility

of limiting the test field to the surface layers of the material gives us a means of comparing the intensity of stresses set up by shot peening. It is possible by this method to pick out pieces with a satisfactory amount of shot peening and to reject those which have not been properly shot peened, or which have had the beneficial surface stresses removed by subsequent mistreatment. To be specific, current at 90,000 cycles is desirable to limit the indications to the very surface. Rounds $\frac{1}{4}$ in. diameter which varied only as to time of blasting gave the indications shown in Fig. 2. (The instrument was deliberately set at zero when testing spring wire known to have had no surface blasting.) The curve flattens off with long times of blasting, which is reasonable, since a maximum stress condition is eventually reached that can be imposed on the surface layers.

Another wartime instance of correlation with internal stresses is in production testing of tracer bodies for 40-mm. ammunition. The tracers are made of high sulphur, free-machining steel. They are loaded under 9000 lb. pressure, and if the

physicals on the steel are a little below normal, the tracer body will crack. The Cyclograph was used to reject tracers having low physicals, or local high concentration of stress before loading. The instrument can also be used on the loading machine to make sure that stresses do not go beyond the elastic limit while shells are being loaded.

Another unusual application was in detecting an armed condition in 3-in. mortar bomb fuzes. If the bomb is properly assembled, the firing pin (which is

enclosed in a brass cap) should be held back flush with the nose. If the bomb becomes accidentally armed, the firing pin comes forward about $\frac{3}{4}$ in. The Cyclograph can be used to determine the position of the firing pin through the brass cap.

There are many other unusual applications, such as this one, which are of very little metallurgical interest. It is always handy, however, to know that such a method is available.

These rather bizarre instances should not let us lose sight of the fact that the principal use the instrument has had in the past, and probably will have in the future, is verifying the constancy of all items in a production lot.

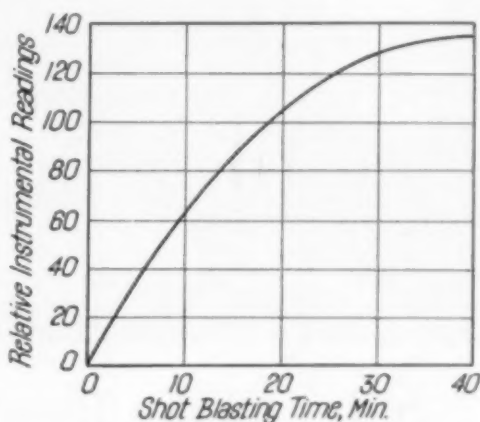


Fig. 2—Relation Between Instrument Reading and Duration of Shot Blast on Steel Spring Wire; 90,000-Cycle Current



Black and white photograph showing the prominent lines of the spectra of pure metallic elements which identify them in the spectrograph.

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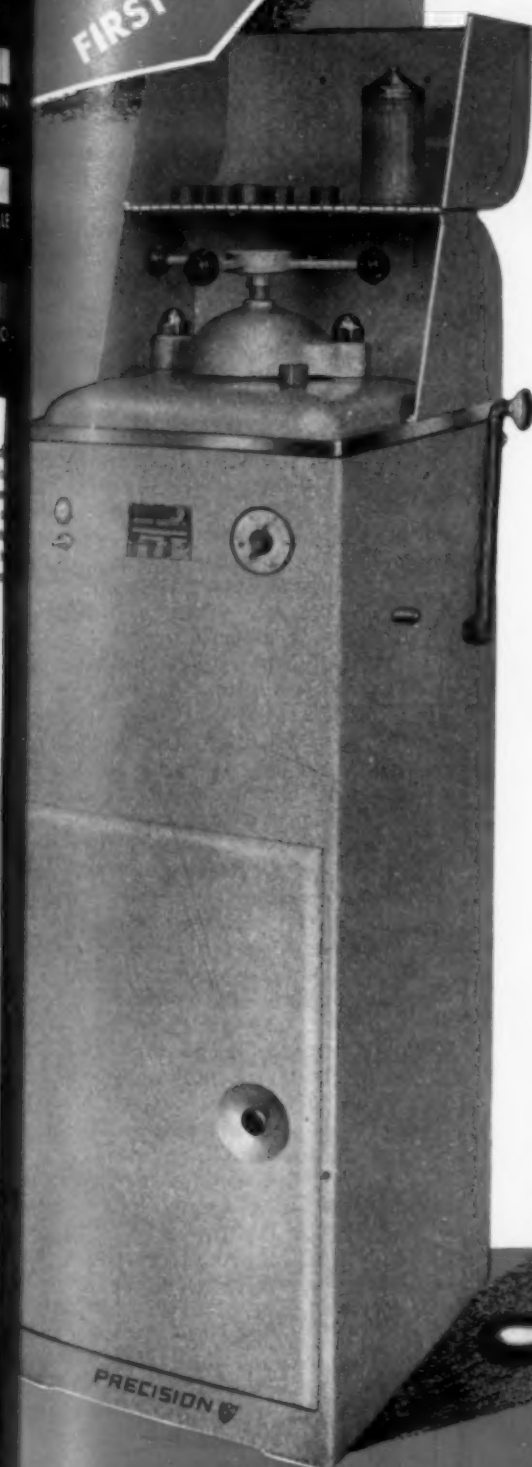
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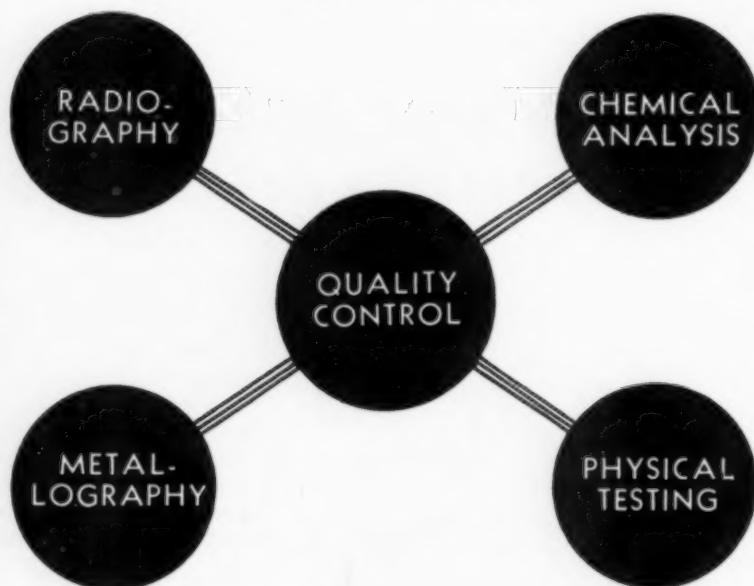
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Notched-Bar Test*

AS A PRELIMINARY to the possible insertion of impact requirements in Australian aircraft specifications, 225 articles published on this subject up to late 1943 were reviewed. There was considerable doubt as to the usefulness of the test, particularly in view of divergence between British and American specifications.

Most of the writers who consider the matter would put notched-bar impact requirements into appropriate specifications as they feel the test is capable of evaluating "general quality and condition" and notch effect where other tests cannot. This includes the effect of variations among different heats of the same type of steel, variations due to differences in grain size, heterogeneity, directionality, the quality of the heat treatment, and variations in the amount of working. It will determine some kind of brittleness (temper brittleness and aging embrittlement) but not embrittlement caused by galvanizing and pickling. However, it is unreliable as an indication of cleanliness. Its utility as a test for resistance of the part to impact loads is of secondary importance while its relation to service conditions and other mechanical properties is quite controversial.

The notched-bar impact test is generally regarded as useful in examining welded joints. The test should also be used in the routine examination of service failures as a preliminary to setting up impact requirements in specifications. In general, its application should apparently be confined to the comparison of different conditions of the same or similar materials.

The most serious drawbacks of the test are its extreme dependence on testing conditions and the fact that it is of no direct use to the designer. So-called inconsistencies in results are probably attributable to variations in the material or to the imminence of a transition range rather than to faults in the test.

Various suggestions have been made to increase the information obtainable from notched-bar tests. Of the tests suggested, the slow notch bend test is most strongly upheld, but it requires a more lengthy procedure.

*Abstracted from "The Practical Significance of Notched-Bar Impact Tests", by A. R. Edwards, Australian Council for Aeronautics, Report ACA-1, June 1944.